

What do stakeholders need to manage for climate change and variability? A document-based analysis from three mountain states in the Western USA

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Abstract Resource managers and governments at all scales are becoming more aware of the challenges and opportunities that climate change and variability pose for their operational goals. At the same time, providers of climate information are learning that simply creating and disseminating information without context does not necessarily serve the needs of decision makers. As a result, calls for new ways of supporting decision making and supplying information abound. Many of these calls suggest that much more consultation with stakeholders is necessary in order to effectively serve their needs and provide usable information. While this is undoubtedly true, there is also in many cases an existing wealth of experience understanding needs of stakeholders that could be assessed before additional interaction is warranted. The goal of this study was to produce a baseline of stakeholder needs with respect to climate-related decision making from existing documents in three interior western states in the USA to examine patterns of needs and avoid stakeholder fatigue. The results suggest that stakeholders express needs for additional data and research, improved communication and coordination among data and information providers, education of their

various publics, and changes to policy and legal frameworks to better manage under a changing climate. Stakeholders express these needs in the context of trying to assess expected impacts, characterize their current and future vulnerability, and manage for future change. The needs and gaps identified suggest opportunities for additional interagency coordination, methods for prioritizing and funding data streams, and partnerships for understanding future climate scenarios.

Keywords Usable science · Stakeholders · Decision support · Climate change

Introduction

In the past several years, the call for climate science to become more relevant to decision makers at various scales has become more prevalent. The US National Academy of Sciences has produced several reports reviewing the need for a stronger connection of the research activity to supporting decisions, including *Informing Decisions in a Changing Climate* (NRC 2009a), *Restructuring Federal Climate Research to Meet the Challenge of Climate Change* (NRC 2009b), and *Informing an Effective Response to Climate Change* (NRC 2010). These reports have emphasized that successful support efforts must “begin with users’ needs” and “link information producers and users,” among other key attributes (NRC 2009a, p. 3). The notion of decision support has now been mainstreamed as one of the four strategic goals of the US Global Change Research Program, which specifically calls for “assessing decision maker needs, capabilities, and science requirements and identifying critical gaps in knowledge and options for a use-inspired research agenda...” among other key activities (USGCRP 2012, p. 60).

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Research over the past few decades has shown that beginning with users' needs and building relationships between the producers and users of scientific information can indeed make scientific information more usable to decision makers (Dilling and Lemos 2011; Cash et al. 2006; Lemos and Morehouse 2005). Information is most usable when it has the qualities of being salient (i.e., relevant to decisions), credible (i.e., seen as authoritative), and legitimate (i.e., in the best interests of the parties involved) (Cash et al. 2003). One of the important ways that researchers and others interested in producing relevant information can do so is to understand the demand for information and where there are opportunities for the supply to better meet that demand (Sarewitz and Pielke 2007).

An important potential side effect of calling for an increased focus on decision support is that stakeholders from both the decision-making and science production sides can be inundated with recurring requests for participation, leading to stakeholder fatigue. Stakeholders were identified as those who plan, manage, support, or make climate-sensitive decisions in one of our identified sectors. This problem can be compounded if the processes in which stakeholders participate are not able to actually address the problems that are important to the stakeholders, whether because the processes lack the power to effect a change based on the input, they are under-resourced, or they are not designed to address the fundamental underlying "failures in democratic institutions and processes" (Kasperson 2006).

The goal of our study was to support the development of a comprehensive baseline of existing knowledge on stakeholder needs as a contribution to building an ongoing capacity in support of climate-related decision making while simultaneously striving to avoid stakeholder fatigue. To that end, we conducted a retrospective study of stakeholder needs and concerns with respect to climate in Utah, Colorado, and Wyoming. This project was conducted as part of the Western Water Assessment (WWA), which is a Regional Integrated Sciences and Assessment (RISA) program of the National Oceanic and Atmospheric Administration, in support of the US National Climate Assessment. There are 11 RISAs around the USA, and they focus on co-producing and disseminating climate-related knowledge to assist regional decision makers with climate-sensitive decisions. The WWA region (Fig. 1) is characterized by a fairly dry climate, variable topography from elevated plains to high mountain peaks, and a large percentage of federally managed public lands, which in turn support recreation, grazing, mining, wilderness and species protection and limited forestry. There is also a significant federal presence in water management, in addition to state and local involvement, because of the region's high

dependence on the Colorado River and associated diversions and reservoirs.

This paper reports our findings on stakeholder needs across three categories: data and research needs, communication and collaboration, and governance and legal needs. We identify the goals of stakeholders and how they see these needs fitting into their ability to manage resources. We conclude with the implications of this study for building an ongoing decision support capability in the region for climate-related decision making.

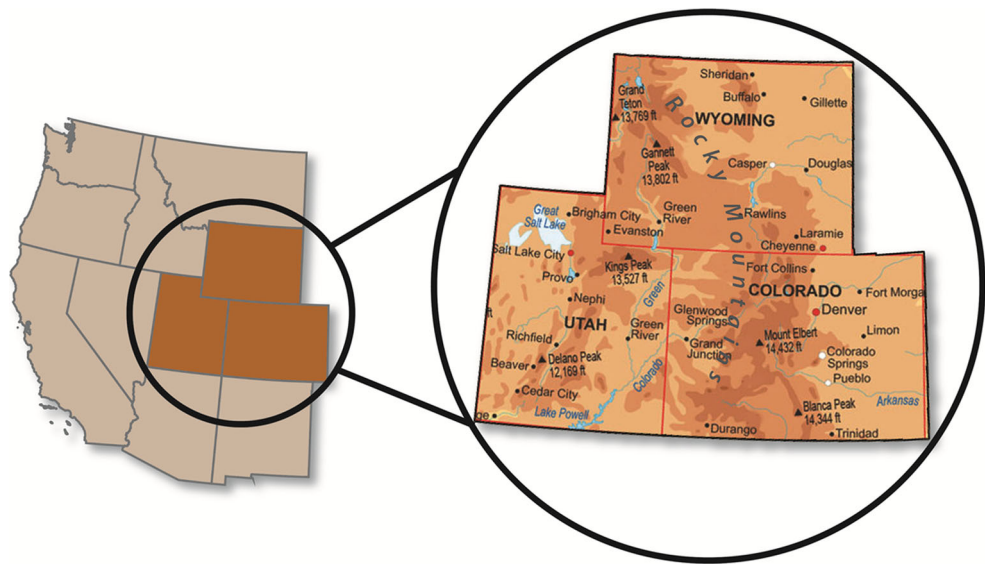
Methods

Our primary approach was to examine documents that had emerged from various processes in the region that had involved stakeholders and were centered on discussion of climate-related concerns. Document analysis, a key method in qualitative research, has the benefit of being "stable, unobtrusive, exact, and available over a long span of time" (Yin 2003, Figure 4.1, p. 86). Limitations of document analysis have been noted, such as that document study results may be biased if the collection is incomplete or the generation of documents is skewed in some way (ibid). Documents do not capture the full discussions that take place within a workshop setting, and also likely to reflect the biases of the main authors.

To obtain documents for our analysis, we conducted extensive web-based searches and queried WWA's network of key informants and collaborators within academia and the public and private sectors. Documents were selected if they primarily represented input from stakeholders outside of the research enterprise itself, identified any type of stakeholder need with respect to climate, and were within the WWA geographic scope. Climate was defined as explicitly mentioning climate, climate variability, or climate change. A document was not included if it discussed weather or other short-term needs with no mention of the term climate. Regional and nationally focused documents were included if they specifically mentioned or identified the WWA region. While some of the documents were generated through processes involving the WWA, many were not. The documents studied included white papers, conference presentations, meeting notes and minutes, reports, academic articles, and any other printed documents made publicly available.

Once documents were identified for inclusion in the study, we classified them by year and sector. Documents emerged from several sectors in our region, including water management, recreation and tourism, agriculture, natural resources/wildlife, and tribal concerns. Some documents were general and covered more than one sector; these were classified as representing multiple sectors.

Fig. 1 The WWA region: the US states of Utah, Colorado, and Wyoming



The procedure for coding and analyzing documents was developed as part of a larger research project in conjunction with two other RISA programs, the Carolinas Integrated Sciences and Assessment (CISA) and the Great Lakes Integrated Sciences and Assessment (GLISA) (Dilling et al. in review). The first step in our document analysis was to record basic information about the document such as the type of document, its geographic region, who was involved in the document's creation, and its relevance to climate. Document criteria were entered into a Microsoft Access Database that included a unique entry ID for each document. We then systematically read each document and isolated what types of needs were identified in each sector. The needs were identified by text explicitly stating the need or desire for a particular climate-related topic (e.g., Future Research Needs). We entered the text from the documents that identified the stakeholder needs into the database for analysis. Next we coded and analyzed the identified stakeholder needs from the Access database using the qualitative data analysis software, NVivo. The NVivo software was solely used to keep track of the coding entered by researchers so that the researchers could identify patterns. We coded the needs expressed by stakeholders into three main categories: (1) data and information (including research needs), (2) collaboration/communication, and (3) governance and leadership (issues that had to do with legal frameworks, mandates, or the role of other sectors in making decisions). These coding categories were developed organically as analysis of the documented needs was conducted. It was unclear at the outset what types of needs might be expressed by stakeholders, thus presupposing coding categories might have proven unproductive or inaccurate. In addition, similar categories were also developed by CISA

and GLISA as part of the larger project. This coding allowed us to analyze the different types of needs, which needs were more prevalent than others, and differences in needs between sectors. Within each of the major categories, sub-categories were used to further code the documented needs. Needs in this study should be thought of as stated needs, or desires, rather than actual needs. We did not have means of assessing the true degree of need for the items or processes mentioned in the documents.

In addition, while we sought to identify documents that focused on needs from a non-researcher stakeholder perspective, researchers were present in some of the workshops that generated documents. Thus, the needs as compiled are not completely free of potential influence from researchers (as an aside, the authors of this paper were not involved in generating the documents in any way). We excluded documents that did not appear to involve stakeholders in their production. We thus feel that our sample of documents was as representative of stakeholder needs as it could be given our methodology, but was not completely free of information-provider influence. In addition, documents were not completely independent from one another because individuals may have participated in the creation of more than one of the documents. Nonetheless, for the purposes of our study, document analysis was the preferred method as we were seeking to harvest existing knowledge over time and over sectors in a systematic way without new burdens for stakeholders; we did not seek to generate a full case study analysis of needs in the region. Finally, we could imagine a follow-on study that systematically examined stakeholder needs in combination with the actual data required to satisfy those needs—this was beyond the scope of our study, however.

Results

General characteristics of the document dataset

As shown in Table 1a, b, fifty-five documents were ultimately selected on the criteria mentioned above to be included in our analysis, spanning 14 years (data collection for 2011 does not represent a full year as we stopped data collection in May of 2011). Table 1a shows that relatively few documents were found before 2006, with an increase in documents in the last 5 years. Documents cited in this article are numbered chronologically, in that the earliest document is labeled Document 1 and the most recent is labeled Document 55. The sector table (Table 1b) shows that about half of the documents found were from the water sector (twenty-six total). Although relatively few documents were found from the agriculture, recreation/tourism, and tribes sectors, many stakeholders from those sectors were involved in the development of documents classified as multiple. Only 17 of the documents were exclusively state specific, with most documents being region specific and including one or more of the WWA states.

Many of the early documents were the result of workshops sponsored by federal agencies under the auspices of the US Global Change Research Program (USGCRP). USGCRP is charged by law to conduct periodic National Climate Assessments, the first of which was completed in 2000. The workshops included participation from diverse stakeholders including academic researchers, local, state and federal government officials, non-governmental organizations, industry representatives, resource managers (especially in the area of water), farmers, tribal government officials, and the media. By the mid-2000s, workshops began to be held by individual sectors such as farming, tourism, water supply and fisheries focusing on particular sector-specific needs as well as by regional governmental organizations such as the Western Governor's Association. A severe, multi-year drought that began in 2002 no doubt increased the region's interest in preparing for and responding to climate impacts affecting critical resources (Lowrey et al. 2009). Toward the end of the decade, a surge in interest in adapting to climate change is evident from the many documents that were completed in 2008, 2009 and 2010. The complete list of documents organized by number referred to in the text can be found in Online Resource 1 and on the WWA website at: http://wwa.colorado.edu/resources/adaptation/stakeholder_climate_needs_docs.html.

Before we describe in detail the needs that emerged, we briefly identify the contexts in which decision makers were operating that often accompanied the needs mentioned. We identified several recurrent themes for why stakeholders were interested in climate information, governance, or communication. First, many needs were expressed in the

Table 1 Documents included in the study, separated by year of publication (a) and from which sector the document originated (b)

Year	Number of documents
(a)	
1998	3
1999	0
2000	1
2001	0
2002	1
2003	2
2004	1
2005	0
2006	6
2007	7
2008	10
2009	11
2010	9
2011 ^a	4
Total	55
Sector	Number of documents
(b)	
Water	26
Tribes	2
Recreation/ tourism	3
Agriculture	1
Natural resources/ wildlife	10
Multiple	13
Total	55

^a 2011 Only through May

context of planning for future resource management in the face of change at multiple timescales. As we will describe next, data and information needs were often expressed in terms informing warning systems, evaluating impacts or planning for uncertain or very different, unpredictable futures. Second, because stakeholders are responsible for managing specific resources, they tend to be concerned about how climate affects their particular sector—thus requiring information that is sector-specific, rather than seeking out general information on climate, even if it is regional in nature. Third, there was a sense that decision making for the near term emerged as a priority—climate variability is already a part of life for many of these stakeholders and many had needs that related to their existing climate context in addition to planning for the longer-term future.

Below we present stakeholder needs grouped into three main categories: (1) data and information (including research needs), (2) collaboration/communication and (3) governance and leadership.

1. Data and information

The document analysis showed that stakeholders across the board had a strong need for new information about various aspects of how climate affected their sectors' resources, and several knowledge gaps were identified. The specific needs to fill these gaps fell into two enabling element categories: needs for the data itself, including current and historical datasets to more refined analytical products, and needs for specific decision support tools such as models and impact scenarios. The need for funding to fill these gaps was mentioned often by stakeholders, especially by tribal and water stakeholders, and most commonly referred to securing additional funding for basic monitoring and data collection.

Knowledge gaps

Biogeophysical baselines Although predictions seem to be emphasized in many climate information programs, in our region, several sectors identified the need for baseline data on current conditions, including the natural resources sector, water sector, and tribal governments. In the water sector, a frequently discussed need was for more baseline assessments of the current state (e.g., assessments of groundwater supplies), historical changes, and the need for a better understanding of current hydrology and climate, including existing water uses and demands. Several documents identified the need to understand the impact of historical variability in climate on natural resources and ecosystems, including wildfire regimes and stream flows (Doc. 51). In addition, tribal representatives highlighted the need for "...baseline data on fish, especially their health and harvest data" (Doc. 3, p. 50).

Impacts One of the most universally recognized knowledge gaps across sectors was the need for more information on the impacts of climate change on resources of interest. Specifically, stakeholders identified the need to know better how climate change would impact agricultural water supplies, crops, and lands, specific species and ecosystems, and hydrology relevant to natural resources and wildlife. For example, one document identified the need to analyze different bird species' sensitivity to climate change, which in turn would help make decisions about prioritizing monitoring and potential management actions (Doc.16). Similarly, another document recommended the use of climate change scenarios and stream flow projections to better understand potential impacts to ecosystems (Doc. 51). The need for studies to understand the impact of climate change on tourism (Doc. 21) and the municipal government sector (Doc. 52) was also acknowledged. For tourism, things like "tourism-climate indices" were thought to be helpful (Doc. 21). In addition, multiple documents suggested more analysis was needed to

determine the likely responses to climate change relevant to tribal communities and reservation ecosystems. One document proposed "...pilot project grants that would allow tribes to gather information to determine impacts of climate change" (Doc. 41, p. 13). Another document discussed the need for native communities to better understand ecosystem responses to climate change (Doc. 3).

Changing extremes Stakeholders expressed needs for more research into changing extremes (droughts, floods, hail, etc.), particularly in the water sector. The needs included not only additional information on current risk but also how those extreme events may change in intensity or frequency, calling for research to "[r]e-evaluate assumptions regarding potential for more extreme events, larger floods and longer droughts, because future variability may be outside the range of our past experience" (Doc. 24, p. 33). Specific to droughts, one document mentioned the need for indicators in helping to manage for extremes (Doc. 31).

Vulnerability assessments Another common theme seen in multiple documents was the need for vulnerability assessments for climate variability and change to identify what is at risk and assist in prioritizing adaptation activities (Doc. 52). For example, in the water sector, one document suggested "...conduct[ing] a portfolio assessment of federal water projects to evaluate the performance of such projects given current conditions and to determine the vulnerability of projects to changing conditions, and increasing vulnerability" (Doc. 24, p. VI).

Patterns of resource demand and use Stakeholders in both the agricultural and water sectors mentioned the need for better data on how water resources were used now, and what level of resources might be needed in the future. For example, one document specifically noted the need for more complete estimates of current consumptive use of water to allow for more equitable management (Doc. 15). Further, examining the additional reservoir storage and conservation measures required to adapt to changing hydrology was discussed (Doc. 15). The need for better analysis of plausible future demands, how future demand and consumptive use might change, and the options that might exist for demand management and conservation were all mentioned.

Uncertainty Uncertainty was a theme that ran through all of the documents, whether stakeholders were speaking of planning for multiple futures or expressing the need to understand the contours of uncertain information better. Some documents reflected a preference among stakeholders for probabilistic instead of deterministic information and analysis. As one documented noted, "[I]and managers need

probabilities, not information in the drawings and not global scenarios. They want this information even if it is messy” (Doc. 2, p. 136). Scenario planning was also discussed as another approach to dealing with uncertainty. Instead of planning for a predicted set of conditions, decision makers should try to prepare for a range in climate scenarios (Doc. 43). Further, it was also mentioned that information be made available about the assumptions that produce the differing climate scenarios (Doc. 28). While the need for uncertainty and probability assessments/analyses was recognized—for example to reduce uncertainty on extreme weather event information—it was also recognized that when uncertainty cannot be reduced or eliminated, it should be incorporated into planning efforts (Doc. 34).

Solutions Surprisingly, perhaps, there were not many documents that reflected the need for solutions as yet—possibly because as described above, the parameters of the problem are not yet fully known. There were, however, mentions of the need for “no regrets” or “least regrets” solutions (Doc. 52), support for crop selection, invasive species management, land use planning, and adaptation planning (Doc. 26).

Data and information enabling elements

Climate and hydrological monitoring data Stakeholders articulated a common need across several sectors for additional hydrologic and climatic monitoring. Several documents reflected stakeholders’ need for additional United States Geological Survey (USGS) stream gages and Natural Resources Conservation Service (NRCS) SNOTEL snowpack sites. Data from these monitoring stations were regarded as essential for not only measuring climate change impacts, but also for supporting early warning systems and reservoir operations. As additional operators begin to fund new sites, there is a need to ensure the consistency in stream gage operations so that data are comparable across different stream gage sites—a difficulty when such gages are expensive to install and operate, and federal funding for higher levels of instrumentation and data collection remain uncertain (Doc. 28). The monitoring needs of other sectors were more diverse and included variables such as temperature, precipitation, soil moisture, and species impacts. The agriculture sector noted the need for groundwater monitoring and better estimates of consumptive use. Many of the documents noted the importance not only of additional monitoring stations, but also secure, long-term funding for continued data collection. In the area of drought early warning, “[p]articipants urged the NIDIS [National Integrated Drought Information System] program to conduct a rigorous assessment of existing drought early warning systems (or pilots)” (Doc. 53, p. 4).

Traditional knowledge and data in tribal lands Stakeholders also identified an opportunity in the data arena to incorporate traditional tribal knowledge into planning and policymaking to address climate change impacts. As one document noted, “[t]he challenge for climate change planners and managers is to harness the palpable diversity, rich indigenous knowledge base, and nascent local-level cooperation of local communities to frame responsive policies” (Doc. 1, p. 67). A further research need in the area of data is “... the training of members of Tribal communities to collect and interpret weather information, including providing for the acquisition, installation, and maintenance of appropriate instrumentation to support the collection and recording of these data” (Doc. 3, p. 79).

Modeling and scenarios Many documents expressed the need for additional and more accurate models and projections tailored to the needs of their particular sector. A document in the recreation and tourism sector expressed that better “...forecasting would provide a better basis for risk assessments and strategic business decisions, including the timing of seasonal openings” (Doc. 12, p. 1425). In the agricultural sector, several documents noted the need for better projections regarding growing seasons and decision support for choosing crop varieties. A more general need was expressed for models that incorporate more of the complexities seen in the region, including dust, snow, convection, and differing ecosystem conditions. Relatedly, there was a need for “...long-term studies... to understand the connections among biological, climatic, surficial process, and hydrological systems in different environments in the Southwest” (Doc. 1, p. 47).

The water sector articulated the broad need for better hydrologic and climatic models and forecasting at both long- and short-term timescales (i.e., better prediction of precipitation changes and effects on water supplies). The water sector was particularly interested in user-driven research that relies on the input of managers and reflects the realities of the water management context. For example, a document in the water sector expressed the need of one municipality in Colorado to incorporate climate models into existing water rights administration to help determine the overall performance of the system (Doc. 9).

Similarly, some documents suggested the need for decision support for managers in the form of relevant tools and assistance in deciding which climate predictions could be incorporated into water supply planning efforts (Doc. 33). The water sector was the only group that expressed a need to understand the *uncertainty* in modeling efforts. Several of these documents noted that differences in projections need to be reconciled in order for them to be useful to water managers (Doc. 18). Paleoclimate data were mentioned as an important area for the water sector where

further research is needed, but one document noted that as of 2009, the date of the document, currently available “[p]aleoclimate reconstructions [are] not being used.... If we can build systems using that variability, we will have greater resiliency” (Doc. 34, p. 76). The other predominant theme seen from stakeholders in the water sector was an issue of scale. For example, a need was expressed for projections to scale appropriately for use by utilities (Doc. 35). Also, “...it is important that climate change modeling be conducted at a much finer resolution, e.g., watersheds and subwatersheds” (Doc. 13, p. 23).

2. Collaboration/communication

Coordination/partnerships

Stakeholders within each sector identified the need for better collaboration and coordination both among themselves, and between different levels of government agencies, researchers, and other entities. Coordination among different scientific efforts (i.e., less fragmentation) was noted in several documents as being important to meet stakeholder needs. Better collaboration was also needed with respect to the sharing of relevant data and information, i.e., government agencies supplying datasets to industry stakeholders. Analysis of water sector documents identified the specific need for decision makers to coordinate better with scientists, including climate modelers. In the tribal concerns sector, the analysis identified a need for more partnerships with relevant federal and local government agencies, as well as with scientific entities, e.g., establishing a “NOAA tribal liaison” (Doc. 47, p. 16).¹ In the natural resources/wildlife sector, the analysis showed a need for an increased number of partnerships among government agencies given budgetary constraints with regard to understanding climate change impacts.

Some documents expressed the importance of long-term relationships and the changing landscape for partnerships and collaboration. For example, several documents expressed the need for securing long-term support and funding for NIDIS, as many stakeholders who plan for drought want to know NIDIS will be sustained in order to develop long-term plans and partnerships (Doc. 53).

One document in the natural resources/wildlife sector noted that increased partnerships among agencies are especially important in their work given budgetary constraints with regard to understanding climate change impacts. In the water sector, several documents also discussed the importance of incorporating academics and science into decision making through new internships,

programs, and grants. One way identified to enable these partnerships was to inform “...state and local water agencies of federal science program grant opportunities and deadlines, so that they can be aware of opportunities to work with academics to develop grant proposals that would support resource management decision-making” (Doc. 18, p. 30).

Dissemination of information

While sometimes conceptualized in different ways, a centralized location or source to obtain climate-related information was a prominent need in many documents. This need was most often expressed as a web-based clearinghouse or portal that would be accessible to all stakeholders in relatively clear and understandable formats. Some sector-specific suggestions included a database for environmental-related literature archived with the ability to digitally cross-reference information (Doc. 7) and an accessible clearinghouse that contains sector-specific climate information (Doc. 21). Similarly, in the water sector, stakeholders sought a centralized source of drought information that can communicate relevant drought conditions (Doc. 31). Further, it was suggested that utility managers be able to easily access the analysis of relevant extreme event information, such as 24-h rainfall and 100-year flood events (Doc. 34). The water sector also called for better early warning information systems as related to climate and hydrologic indices, i.e. snowmelt timing and spring runoff. In addition to the need for a centralized location of information, many documents called for better clarity of information and clearer expressions of uncertainty. Tribal stakeholders noted that this information and related educational materials should be accessible by tribes (Doc. 3). Local and state decision makers also expressed the desire to coordinate more closely—both among themselves and between different levels of government—and be more able to easily access the resources that the federal government could provide in the area of information on climate science, as local governments are often making decisions that may be influenced by climate but do not always have the available knowledge.

Beyond simply providing a clearinghouse for existing data, some stakeholders felt that coordinated research and service efforts were needed to address this issue. Water sector stakeholders called for the creation of climate-related research centers, such as a National Climate Service (Doc. 45, p. 4) or a Colorado Water Institute (Doc. 17, p. 8–21); the latter entity was established through an act of the US Congress and the Colorado State Legislature shortly after the document was written (www.cwi.colostate.edu).

As has been noted in other studies, stakeholders noted the importance of paying attention to how data are

¹ Note that as of 2013, NIDIS, the National Integrated Drought Information System has now established a NOAA tribal liaison.

presented, because presentation impacts usability or the perception of usability. For example, a document from the water sector pointed out that, “[d]ownscaled data must be provided in formats that are useful to water managers (e.g., climate modelers use gridded data, while water managers use discrete data points)” (Doc. 28, p. 10).

The overall message that the documents from all sectors seemed to convey is that there is a substantial amount of relevant information available, but not necessarily in accessible or usable formats. Consolidating climate-related information, including better expressions of uncertainty, would improve the ability of stakeholders to incorporate climate into decision making.

Communication and public education

Stakeholders expressed the need for both better communication between scientists and stakeholders (farmers, Tribal elders, water managers/users) and between experts or stakeholders and the public. To achieve the former, one idea was to hold workshops specific to climate change adaptation or have regular teleconferences and webinars (Doc. 55).

The call for greater public education was evident across all sectors, although the types of information the stakeholders wanted the public to be educated about differed slightly among the sectors. For example, the natural resources/wildlife sector documents called for more public education regarding the likely *impacts* of climate change, i.e., changes in fire activity, pollution, and invasive species. In the water sector documents, several needs related to coping with the problem by emphasizing to the general public the importance of drought management and water conservation (Doc. 31). Others in the water sector emphasized better education about the *connection* between water and climate change—in other words how carbon dioxide emissions are linked to the hydrologic cycle (Doc. 17). The tribal sector included broader goals such as “[c]limate-related education focused on promoting healthy lifestyles and environmental consciousness” (Doc. 3, p. 38).

3. Governance and leadership

The water sector identified some important needs at the intersection of water supply and the system of water rights allocation common to the region. Because this system is climate-sensitive, several documents acknowledged the need to investigate possible impacts on water rights, and the timing of water rights, as snowpack is projected to be reduced in the future and snowmelt to occur earlier in the year. Stakeholders felt water laws must be examined to understand their flexibility and ability to handle various climate change impacts (Doc. 24).

Water is also a factor in legal requirements for certain endangered species, and thus, stakeholders identified the need of the state to understand how climate change may impact federal regulation (Doc. 52), and the need to determine whether water rights and allocations could be used for protecting ecosystems and species. The latter need was expressed in regard to the possibility of purchasing water rights to protect grouse habitat and other threatened and endangered species. One document did mention the need to review the legal allocation of water rights independent of climate change to assess current inequities and inefficiencies (Doc. 4).

The natural resources/wildlife sector expressed needs mostly relating to improved invasive species management and land use planning especially in terms of providing the flexibility to respond to potential climate change impacts (Doc. 1). The need for an approach for protection of public lands that incorporates adaptation concepts and flexible management was also articulated by one group: “...we suggest here a triage approach in which large blocks of undisturbed public lands are protected immediately, while also creating an interagency and interdepartmental ‘climate commission,’ advised by a standing body of scientists, to devise and refine continuing solutions as our understanding of climate change and its impacts on public lands evolves” (Doc. 42, p. 3).

A final important governance theme that emerged from several documents was the need for tribes to be represented in discussions of climate mitigation or adaptation policy. This need extends not only to policy but also to data collection and building capacity among tribal communities for participating in the science and decision making with respect to climate change.

Discussion and conclusions

Over the past decade, stakeholders from the WWA region have identified many needs related to climate variability and change. Stakeholders were interested in understanding the potential impacts of climate change and what their vulnerabilities might be, but there also seemed to be a gap in understanding some of the ways in which climate affects resources in the region even in the present day. In addition, beyond issues such as data, modeling, and scenario development that were of great interest, stakeholders identified a need for more coordination, communication, and collaboration in the region. Several documents suggested that the current research effort, and the dissemination of its information, is fragmented, or at least it appears so to stakeholders. This fragmentation—or perception of fragmentation—suggests that there is substantial capacity to provide the needed data, modeling, and knowledge, but

that stakeholders may be encountering barriers in locating data, finding experts, or simply knowing whom to contact as a first step. The stated need for a clearinghouse suggests that some level of collection or organization might be needed to help stakeholders make best use of the resources already available. On the other hand, we did not evaluate what currently exists and how accessible it is, so we cannot say for sure why this need emerged and what the remedy might be. A future study could examine the supply of climate information in a comprehensive manner and how it relates to the demand (as expressed here by needs) to understand where the opportunities exist to fruitfully engage between suppliers of knowledge and the potential users on the issue of coordination and access to information (e.g., Dilling 2007; Logar and Conant 2007).

Another key implication from the study is that the knowledge that is created to fill the needs of stakeholders in this region should be produced through collaboration with stakeholders in order for it to be able to meet these needs. Many of the knowledge needs such as the future impacts of climate on water allocation, tourism, ecosystem management, municipal responses, and tribal resources demand attention to the details of the resource being managed and the context in which decisions are being made. Vulnerability assessments, of which there have been a few in the region, are another type of need that should be similarly conducted in a co-produced manner. An evaluation or process to engage stakeholders on their needs for understanding regional vulnerabilities would help to inform what direction might be most productive in meeting this need.

It is important to note that almost half of the documents found in this analysis were from the water sector, which is most likely due to the region's dependence on surface water for municipal, industrial, and agricultural supply. Specific inter-sector differences have been discussed throughout the paper, but across the board, it appears that the water sector has more specific and advanced needs. For example, most sectors discussed the general need for better models and projections to assist in decision making, but in the water sector, it was also expressed that these models need to be developed in conjunction with water managers in order to incorporate more than just climate variables (e.g., water allocation rules, and timing of decision making). Further, only the water sector documents expressed the need to better understand the uncertainty in climate models and how to incorporate these uncertainties into decision making. A more robust inter-sector analysis would be ideal, but given the relatively few documents in some of the other sectors it would be difficult to identify additional broad differences or similarities from our particular dataset.

More generally, any attempt to meet the diverse needs found in this research suggests that boundary organizations (McNie 2007) that connect the science production and

analysis to decision makers and stakeholders are likely to be very important to the region moving forward. Such boundary organizations, "...link different social and organizational worlds to foster innovation, provide two-way communication among multiple sectors and integrate production of science with user needs" (Feldman and Ingram 2009). Some of the boundary organizations already operating in this region at the university or federal level include the Colorado Water Institute at Colorado State University,² the Department of Interior's Landscape Conservation Cooperatives (LCCs)³ and Climate Science Centers (CSCs),⁴ NIDIS,⁵ and WWA.⁶ Some of these entities are relatively new and undoubtedly emerged to address the needs articulated in the documents studied, such as CWI and NIDIS, which were specifically mentioned in some documents. NIDIS, for example, was created in 2006 and began an evaluation process in 2013 in an effort to help understand its efficacy (Chad McNutt, personal communication). It was beyond the scope of our research to systematically evaluate how the needs identified in this analysis are being filled or may be filled, and how coordination may be better achieved among all of the regional entities. Such an analysis would likely be a useful next step in this area.

It is also clear that it may not be enough to simply identify needs to have those needs met. For example, many stakeholders noted the need for additional USGS stream gages and NRCS SNOTEL monitoring sites, but lack of funding is a large impediment to furthering those programs. In fact, data collection from some current USGS stream gages is being discontinued due to federal budget reductions beginning in 2013. Given these budget constraints, it is unclear when or whether additional funding would be available from federal sources. One option to overcome this barrier might be to expand funding partners to include more regional and local entities, for whom the new data would be most beneficial, although efforts would need to be taken to make sure the data are comparable with the existing network to maximize the overall dataset

² The Colorado Water Institute focuses "...water expertise of higher education on the evolving water concerns and problems" faced in Colorado. <http://www.cwi.colostate.edu/>.

³ LCCs were established to share "...science to ensure the sustainability of America's land, water, wildlife and cultural resources." <http://www.doi.gov/lcc/index.cfm>.

⁴ CSCs were established to provide scientific information, tools and techniques that stakeholders can apply to climate responses at regional-to-local scales. <http://www.doi.gov/csc/index.cfm>.

⁵ NIDIS was established to provide information to stakeholders in order "...to move society from a reactive response to drought to a proactive stance." <http://www.drought.gov>.

⁶ WWA is a NOAA-funded RISA program research program "...that addresses societal vulnerabilities related to climate, particularly in the area of water resources." <http://wwa.colorado.edu>.

usefulness. Another issue is that some needs may simply not be feasible to meet, whether because of the limits of scientific capacity or the limits of institutional mission and jurisdiction. For example, stakeholders would like for climate models to become more certain and have greater skill at scales of relevance, but it is unclear whether these uncertainties will ever be reduced or eliminated (Dessai et al. 2009), suggesting that investing in developing options that are robust to multiple futures might be a reasonable substitute (Lempert et al. 2004; Wilby and Dessai 2010; Mahmoud et al. 2009). The documents in general did not take on the issue of how to ensure that the needs identified would actually be met.

This document study is limited in that it can only report on what is available in the documents, and of course documents are only one distillation of a conversation that has taken place. Some information is likely to have been overlooked or excluded in the process of finalizing the text of each document. The processes that led to these documents undoubtedly did not include all the potential stakeholders that could have been included—they thus represent a limited group of perspectives. Needs that might emerge from a single workshop or even a series of workshops do not necessarily represent the needs that are feasible or that might be discovered through a much longer process of true iterativity and co-production. Research that produces usable results is often defined jointly by researchers and stakeholders, through a process that gives weight both to the decisions to be informed and to the skill or data that can be realistically expected from the process of inquiry (Dilling and Lemos 2011). Some of the documents in this study were undoubtedly the result of such a long, engaged process (e.g., Lowrey et al. 2009) but others may not have been.

Such a study is also limited by the searching method, and one cannot know whether additional documents from the same time period were overlooked. In addition, the paucity of documents from the early portion of the time period in our study did not allow for an analysis of how needs might have changed over time—what we can say is that there was a strong surge in interest in climate in the latter part of the time period. Follow-on work such as a survey, additional workshops, or systematic review of ongoing co-production knowledge processes in the region would be needed to see whether needs have significantly shifted. However, our goal in this study was to avoid fatiguing the stakeholder base by taking advantage of what had already been shared.

Overall, document analysis appears to be a useful method of identifying a range of stakeholder needs, and as part of a larger suite of tools and methods, can help to lay the groundwork for building and evaluating regional capacity to support climate-related decision making. Such a study can identify the broad categories of needs that should be

investigated more thoroughly through future engagement processes and may help to serve as a baseline (along with other metrics) for evaluating progress for new decision support services. Coupled with a companion analysis of the network of information providers and information provision, opportunities for improving decision support in a region can be identified. While the details of providing decision support are highly context-specific, our analysis may provide an entry point for building future ongoing capacity for improved climate-related decision making.

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