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Use of water decision-support tools for drought management

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ABSTRACT

Climate is changing in ways that may significantly affect the provision of hydrologic ecosystem services in arid or semi-arid regions. To answer this challenge, there has been an effort to increase the adaptive capacity of organizations that manage water and the land-uses water supports. Governmental and non-governmental organizations (NGOs) managing large landscapes in the United States Northern Rockies region have access to a variety of water decision-support tools, such as indicators of precipitation and snowpack, which could increase their adaptive capacity to manage hydrologic ecosystem services under changing conditions. Yet little is known about the use of decision-support tools in this region and how tools could be improved. With the aim of informing future tool development and addressing information-use gaps, we conducted semi-structured interviews with representatives of federal and state agencies and NGOs to 1) identify which tools are being used, 2) describe tool-supported management actions across different types of organizations, and 3) determine "usability" criteria managers consider when adopting a climate tool. Through qualitative analysis, we found multiple types of tools being used, including processes and frameworks, data and models, and geospatial or web-based tools. We also identified several criteria that study participants used to assess whether or not to use a tool within their organization, including tool accuracy, robustness, extendibility, interpretability, capacity, and institutional fit. This study suggests that increased communication between tool developers and end-users, with a focus on tools' relevance and ability to support management actions, could improve tools and increase the adaptive capacity of users. This research also points to the need for multiple lines of future research including how to improve the fit between organizational goals and water tools.

1 Introduction

Climate change is increasing the frequency and severity of water shortages and droughts in many parts of the world. Droughts affect fish and wildlife species abundance and movement, forest and rangeland productivity, agricultural production and livelihoods, and community well-being (Thomas et al., 2013; Wilhite et al., 2007). To answer this challenge, governments and practitioner groups have led efforts to increase the adaptive capacity (the ability to adapt to the effects of hazards (Smit and Wandel, 2006)) of organizations that manage water and the land uses water supports (Adger et al., 2003; Ficklin et al., 2015). Decision-support tools, including those specific to water management, have the potential to increase adaptive capacity by providing information needed to plan preventative action and adaption options (Prokopy et al., 2013). Unfortunately, environmental decision-support tool development has largely been disconnected from the behavioral, cultural, institutional, and cognitive context of users (Wardropper et al., 2021). Because of this disconnect, these tools are often under-utilized or unused because they do not match how managers use data and make decisions (Lemos et al., 2012; McIntosh et al., 2011; Singh et al., 2018; Walling and Vaneeckhaute, 2020). We argue that social science research is necessary to understand the motivations, barriers, and decision processes of decision-support tool users to make tools useful and usable (Prokopy et al., 2013).

Decision-support tools for water management ("water tools" henceforth) can aid planning to achieve landscape management and conservation goals like drought resilience (Keyantash and Dracup, 2004; Schwartz et al., 2018; Vicente-Serrano et al., 2009). Drought resilience is the ability to recover from drought through short-term coping strategies and long-term adaptive capacity (Scanlon et al., 2016). We define water

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tools as methods and other knowledge resources (e.g., products, websites, bulletins) that integrate information on water, climate, and weather to facilitate decision-making for specific users or objectives (NOAA, 2021a; Palutikof et al., 2019), and particularly focus on water tools for drought management. We consider three types of water tools: "Processes and Frameworks"—cohesive sets of activities, tools, and guidelines used to structure water shortage or drought planning; "Data and Models"—raw or algorithm-based climate, weather, or water information; and "Geospatial or Web-based Tools"—tools with an online interface component that allows users to interact with the data to meet their own goals (Palutikof et al., 2019; Schwartz et al., 2018). Past social science research has documented the usefulness of water tools in multiple contexts, including drought planning by ranchers (Haigh et al., 2021), reservoir management (Hannaford et al., 2019), and power generation planning (Lopez and Haines, 2017). For instance, Hannaford et al. (2019) conducted participatory workshops with potential users of drought information in the United Kingdom to assess the specific needs of users, what triggered their use of drought information, and how that information was used within different organizational contexts.

Why and in what ways do users interact with environmental decision-support tools? Past quantitative studies have reported demographic predictors of why different types of individuals use information for decisions, including mobile internet consumers (Venkatesh et al., 2012) and agricultural producers (Rose et al., 2016). Likewise, public administration scholars have investigated policy and organizational factors associated with the use of environmental information to support decisions in organizations (Wardropper, 2018; Wardropper and Rissman, 2019). Yet computer scientists and social scientists alike have called for more detailed investigations (Hewitt and Macleod, 2017; Ritter et al., 2014; Wardropper et al., 2021). From an environmental management standpoint, Schwartz et al. (2018) argue that researchers must better understand how and why decision-support tools are used by conservation organizations to inform different stages of adaptive environmental project management, including project scoping, operational planning, and learning. This detailed understanding is needed because there are multiple challenges that might impede the use of these tools, including lack of organizational capacity to acquire, use, or implement changes based on new information (Brody et al., 2010; Glaas et al., 2010) or a lack of fit between the framing or outputs the tool and the needs of a particular organization (Whittaker et al., 2021). At the individual level, barriers to using environmental decision-support tools might include concerns about information uncertainty (Coppock, 2020) or disconnects between Western scientific and local ways of understanding the environment (Yeh, 2016). Indeed, there have been few qualitative social science studies conducted to understand the contextual and process-based reasons why environmental decision-support tools are used and for what purposes.

Different criteria have been proposed to improve the use and usability of environmental decision-support tools. To improve drought indices, tools that provide numeric representations of drought severity using several variables (e.g., precipitation, temperature, soil water), engineers Keyantash and Dracup (2002) proposed several evaluation criteria. These include robustness (usefulness over a wide range of conditions), tractability (the practicability of creating an index), transparency (how much of the rationale and process are shared), sophistication (high-level technical calculation), extendibility (usefulness across time), and dimensionality (physical units used to describe the world). Social scientists have also suggested evaluation criteria for water tools including the accuracy of outputs and the capacity needed for an organization to use the tool (Hannaford et al., 2019; Lopez and Haines, 2017). Furthermore, research specific to organizational use of decision tools focuses on "institutional fit" as a criterion for decision tools, that is, the fit between the problem the tool is meant to address and the institution's goals and structures (Borowski et al., 2008; Epstein et al., 2015). Though these and other evaluation criteria have been proposed for water tools, evaluation of environmental decision-support tools often gets overlooked (Wong-Parodi and Small, 2021).

The US West is experiencing a new climate "normal" of increased dry weather, including more frequent and severe drought (NOAA, 2021b). Scholars have called for improved tools to aid in day-to-day as well as "high stakes" decisions such as drought declarations (Abatzoglou et al., 2017). Within this environmental context, the long-term aims of our applied work are to inform future water tool development for responding to drought and address information-use gaps across different organizations. The objectives of the present study were to: 1) determine which water tools have been used by organizations for large landscape drought management, 2) describe tool-supported management actions across different organizations, and 3) determine usability criteria managers consider when adopting a water tool. We used qualitative interview methods for this study, which allowed participants to explain their answers in detail while linking institutional and cognitive contexts, facilitating a more holistic and deeper understanding of the issues (Sandelowski, 2000). We conducted our study within the High Divide region of Idaho and Montana, situated within the larger Northern Rockies landscape where federal and state government agencies and non-governmental organizations (NGOs) have a history of collaboration to increase social-ecological resilience to drought. In the next section, we describe the study area, data collection and data analysis procedures; in Results, we present our main findings regarding water tool use and decision criteria following our three research objectives; and in the Discussion and Conclusion section, we discuss how our findings might contribute to the improvement of water tools.

2. Methods and materials

2.1 Study area

The High Divide region, a 25-million-acre region across Idaho and Montana, provides an excellent opportunity to study water tools used for large landscape drought planning and management. The broad range of landscape types, species, and human livelihoods present in the region provide a varied water tool user group, which allowed this team to investigate how different behavioral, cultural, institutional, and cognitive factors affect water tool use and usability. The region sits within the Greater Yellowstone Ecosystem (GYE), the Central Idaho Wilderness (CIW), and the Crown of the Continent Ecosystem (COC) (Fig. 1) and supports diverse vegetation communities including sagebrush steppe, forest, and rangeland systems, while also containing the headwaters of the Missouri and Columbia rivers.

The region provides spawning habitat for anadromous fish from the Pacific Ocean and is important for wildlife connectivity between protected areas such as the GYE, CIW, and COC for large carnivores, ungulates, and fish (Carroll et al., 2012; McClure et al., 2017, 2008; Shafer, 2015). Private ranchlands, which make up a higher proportion of all land area when compared to neighboring regions, are vital to connectivity between public lands and are becoming increasingly important within the context of increasing climatic and anthropogenic pressures on ecological systems (Belote et al., 2016; Graves et al., 2019; McClure et al., 2017).

In the US Northern Rockies of Idaho and Montana, drought is a natural part of climate conditions, particularly in rangeland-dominated ecosystems (Brown et al., 2016; Whitlock et al., 2017). Yet climate projections to the end of the century suggest decreased precipitation in certain times of the year (Whitlock et al., 2017), decreased snowpack resulting from long-term warming trends (Abatzoglou et al., 2017), increasing surface temperatures, changes in runoff timing, and loss of soil moisture-holding capacity due to historic unsustainable use of rangelands (Thurow and Taylor, 1999), all of which will exacerbate drought "when and where it occurs" (Whitlock et al., 2017). Indeed, according to the National Oceanic and Atmospheric Administration's (NOAA) decadal update, the "new normal" in the US West for the period 1991 to 2020 is drier compared to the previous thirty-year period from

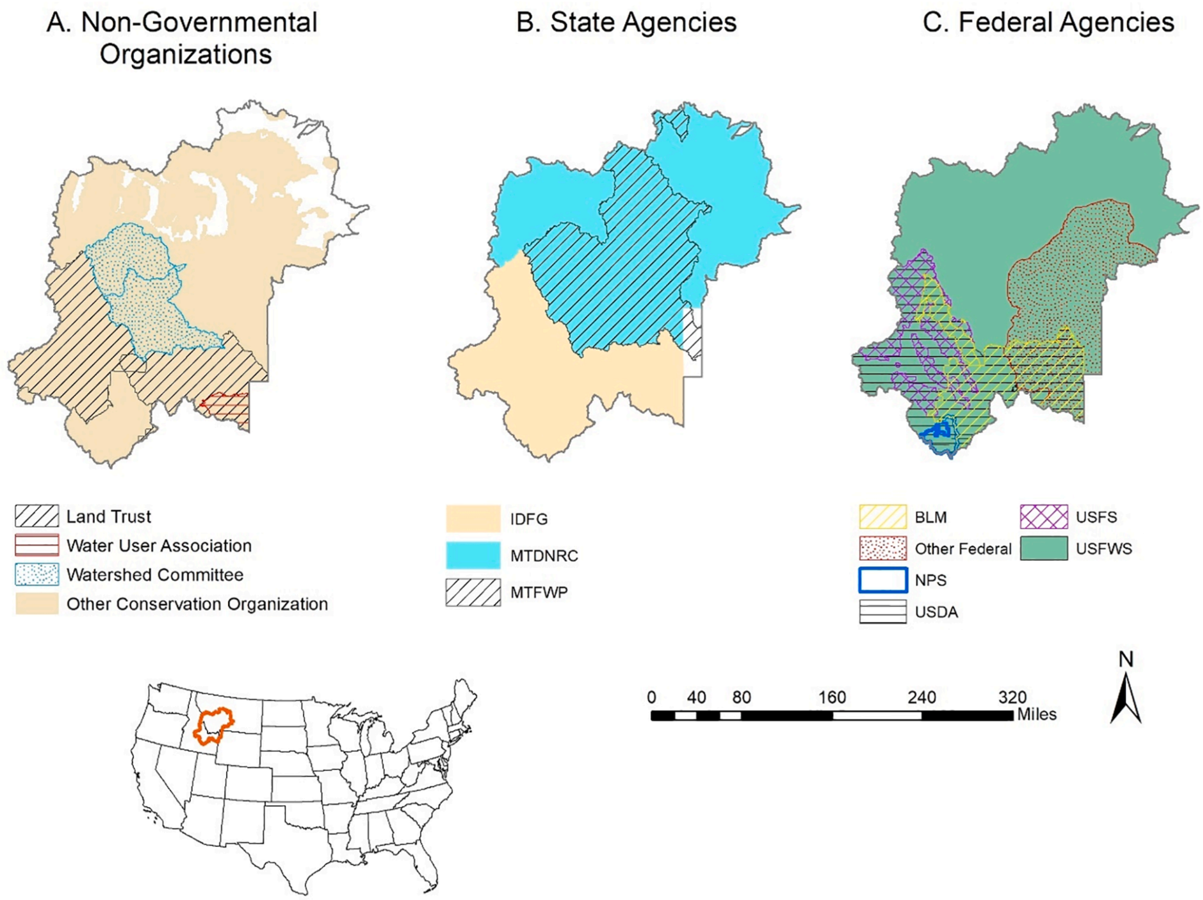

Fig. 1. Location of the High Divide region spanning Idaho and Montana in the United States. Location of (A) Non-Governmental Organizations, (B) State Agencies, and (C) Federal Agencies.

1981 to 2010 (NOAA, 2021b). Increasing drought resilience has been identified as a goal of multiple governmental and non-governmental management organizations in the Northern Rockies region (Crausbay et al., 2017; High Divide Collaborative, 2020a).

For this research, we partnered with the High Divide Collaborative (HDC), which defines itself as "an effective partnership of public land managers, state wildlife agencies, landowners, local community leaders, scientists, and conservation groups working together to conserve and restore lands of importance for local communities and to protect ecological integrity at the landscape scale" (High Divide Collaborative, 2020b). Drought resilience, described as "clean and abundant water for headwaters fisheries, wildlife, healthy riparian communities, and human uses" is one of eight priority themes that direct the work of HDC (High Divide Collaborative, 2020b).

2.2. Data collection

Data collection consisted of 31 semi-structured interviews (i.e., interviews were guided by a script, but included open-ended questions to allow for emergent responses) with federal, state, and NGO employees working in the High Divide region. Interviewees were selected based on their attendance at High Divide Collaborative annual stakeholder meetings, held in Dillon, Montana in 2018 and Idaho Falls, Idaho in 2019. The HDC annual meeting brings together regional stakeholders to discuss current trends, challenges, and opportunities regarding issues such as drought resilience, sustaining agricultural livelihoods, and wildlife connectivity. We sent requests for interviews to non-profit and federal and state agency meeting attendees via email, with one additional email sent one to two weeks after initial contact if no response was received. If multiple employees from a single organization attended the HDC meeting, we invited individuals with a leadership role or with water and/or drought management responsibilities for an interview. Additional interviewees who worked in the region but were unable to attend the HDC meeting were subsequently added via snowball sampling. Interviewees belonged to a range of federal, state, and non-governmental organizations, including land trusts, watershed committees, and water user associations, as outlined in Table 1 (for more detail

Table 1
Summary of number of interviewees by organization types.

Organization Type	Organization Subtype	Number of Interviewees
Non-governmental organizations	Land Trust (LT)	4
	Watershed Group (WG)	4
	Water User Association (WUA)	1
	Conservation Organization (CO)	8
State Agencies	Idaho Fish and Game (IDFG)	4
	Montana Fish Wildlife and Parks (MTFWP)	1
	Montana Department of Natural Resources Conservation (MTDNRC)	2
Federal Agencies	US Forest Service (USFS)	2
	National Park Service (NPS)	1
	US Fish and Wildlife Service (USFWS)	3
	Bureau of Land Management (BLM)	2
	United States Department of Agriculture (USDA)	1
	Greater Yellowstone Coordinating Committee (GYCC)	1

see Supplemental Material Table 4).

Each interview lasted approximately one hour and was recorded with the participant's permission, per our Institutional Review Board protocol, the University of Idaho IRB protocol 18-009. Most interviews were held in person at the interviewees' place of work, though several were conducted via video conference if an in-person meeting was not possible. We acknowledge that this difference in medium (in-person versus video conference) could have resulted in different levels of participant comfort with the interviewer and therefore the quality of the responses given. Some interviewees supplied supplementary documents during interviews, such as copies of management plans, which were used as complementary contextual information during analysis.

Table 2 summarizes interview guide questions by objective. The interview guide was developed based on our research objectives and a preliminary literature review of water tools used for drought management in the region. We primarily focused questions on drought indices, which are a type of water tool important in this region for responding to water availability concerns, but interviews often included a wide array of other water tools that our participants used. The guide included both open-ended questions to provide opportunities for inductive analysis and closed-ended questions based on literature (e.g., proposed evaluation criteria for water tools) that would allow for deductive analysis. Objectives 1 and 2 have the same associated interview questions since we found responses to the specified questions could be used to inform either objective. The interview guide question related to usability criteria (Objective 3) was adapted from Keyantash and Dracup (2002).

2.3. Data analysis

Interview transcripts were analyzed with the software NVivo. We used an iterative coding approach that included a first round to identify overarching themes for each of our research objectives, and then secondary coding to organize and find emergent themes (Tracy, 2012). Our approach included both deductive and inductive coding, meaning we had initial expectations about the types of responses we might find, but allowed for new information to emerge from the transcripts. We identified and assigned codes by organization to all water tools to satisfy Objective 1. We excluded any tools that were used to monitor water *quality,* which was outside the scope of our study. To determine how water tools were applied in management settings (Objective 2), we created a typology of tool usage across different organization types and associated management actions. Lastly, we coded the transcripts for managers' tool usability criteria (Objective 3). The initial criteria were provided in our interview (adapted from Keyantash and Dracup's (2002) evaluation criteria), but we also asked for additional criteria our participants used, which resulted in two additional criteria that were of clear importance to managers, institutional fit and capacity.

Table 2
Research objectives and associated interview questions.

Research Objective	Associated Interview Questions
1. Determine which water tools have been used in non-governmental organizations and state and federal agencies. 2. Describe management actions supported by water tools across organization types.	• What are the primary management priorities in your organization? • What types of information does your organization use to make decisions about or plan for environmental changes? • What resources has your organization used for drought mitigation planning in the past? How and when were they used? • Has your organization used drought indices in the past or currently for drought mitigation planning? • Has your organization used drought indices to predict or monitor any drought impacts?
3. Determine usability criteria for water tools used by managers in landscape management organizations.	• Please rank the following tool criteria according to how important each one is for whether you use a particular tool: Extendibility, Accuracy, Robustness, Transparency, Ease of Interpretation, Other. Now, let's walk through why you ranked them in this way. • What are the barriers, or potential barriers, to using drought indices in your organization?

3 Results

3.1 Use of water tools in management organizations

We identified approximately 65 water tools used by landscape management organizations in the High Divide region. These tools fell into three broad categories including Processes and Frameworks (Supplemental Material Table 1), Data and Models (Supplemental Material Table 2), and Geospatial and Web-based tools (Supplemental Material Table 3). The most frequently mentioned tools are summarized in Table 3; data and Models were the most frequently mentioned type of tool. For example, snowpack data presented by Snow Telemetry (SNOTEL), which automates data collection from high mountain watersheds used to monitor snowpack and other climate conditions, is used by the US Fish and Wildlife Service to guide water releases from dams for bird habitat (Table 3; Supplemental Material Table 2).

Tool-supported management was specific to organizations and their respective management priorities (Supplemental Material Table 1, 2, 3; Table 3). Tool-supported management ranged from aiding in understanding conservation action effectiveness to determining individual species management. Tools were often leveraged for other purposes aside from drought management. For example, tools were used to inform fisheries management, aid in species and habitat modeling, and inform conservation easement acquisitions and projects. Drought preparedness was recognized as important in most organizations and was included at least indirectly in planning processes.

3.2. Usability criteria for climate tool use

Interviewees discussed the levels of importance they ascribed to the water tool usability criteria we inquired about explicitly and added other criteria of their own (Table 4). Below, we draw on our interview data to describe the perceived role and importance of each criterion for study participants. Interviewees' reflections on usability criteria segued into discussion of the challenges associated with certain water tools.

3.2.1 Tool accuracy

The accuracy of a water tool was defined as the degree of agreement between tool output and measured conditions at the relevant geographic scale. Federal agency representatives rated this criterion important, but understood the difficulties of achieving precise and accurate predictions using one component of many water tools used in the region—climate models—as described in the following quote:

> Well, [accuracy] is important, but I mean, I've been involved in science my entire life. A model's only as good as the data that we put into it. I realize that we're limited, and we have a changing climate. And this spring, for example, was supposed to not have been this wet, and then we ended up getting a lot more moisture early in the summer. We're not going to [say], 'You got it wrong.' We're not going to degrade someone for that. They're just going off the best data that they have, and then we're doing the same thing. Adaptive management is something that we always must keep in mind. [Federal Agency 4]

This federal agency employee worked primarily with vegetation

Table 3
Most frequently mentioned water tools by type. One example organization where the tool is used is given, with associated management actions guided by the tool in that organization.

Tool Type	Tool	Example Organization	Organization Type	Example Tool-Supported Management Action
Processes and Frameworks	Vegetation Monitoring	Henry's Fork Foundation	NGO	Used to monitor the effectiveness of conservation practices like strategies to reduce irrigation demand.
	Rainfall/Streamflow Monitoring	Montana Fish Wildlife and Parks	State	Used to implement water management directives for species protection and inform watershed committee decision-making.
Data and Models	Climate Science Publications	Teton LegacyWorks, Teton Water Users Association	NGO	Use supports landscape familiarity, guides conservation projects, and is used to inform grant writing.
	Streamflow Data	Big Hole Watershed Committee	NGO	Use informs conservation effectiveness and helps determine when to enact drought plan steps.
	Snowpack Data	US Fish and Wildlife Service	Federal	Use guides infrastructural water release for wetland bird habitat.
	Climate Forecasts	Idaho Department of Fish and Game	State	Used to raise awareness, inform monitoring, and direct work. Also used to generate a range of potential impacts on areas or species.
Geospatial and Web-based	Climate Resilient Lands Layer: Conserving Nature's Stage	Sagebrush Steppe Land Trust	NGO	Use informs where to focus land acquisitions and projects.
	River Conditions Webpage	Big Hole Watershed Committee	NGO	Use informs when to enact drought plan steps.
	Natural Resources Conservation Service Soil Maps	Henry's Fork Foundation	NGO	Use informs where to implement irrigation efficiency strategies.

Acronyms: NGO (Non-governmental organization); CO (Conservation Organization); USFS (United States Forest Service); USFWS (United States Fish and Wildlife Service); LT (Land Trust); WUA (Water Users Association); WG (Watershed Group); IDFG (Idaho Department of Fish and Game); MTFWP (Montana Fish Wildlife and Parks); BLM (Bureau of Land Management).

restoration projects and relied heavily on forecasts to plan management and planting sessions, yet understood the difficulties of a consistently accurate model.

State agency employees rated the importance of accuracy over other criteria such as interpretability and extendibility. For instance:

> If you use [StreamStats] to make management decisions, you're not necessarily using accurate measurements and you can make bad calls because of that. So, I guess … accuracy over readability. [State Agency 3]

StreamStats is a tool described as relatively user-friendly and therefore an appealing tool for managers with less technical tool training. NGO representatives added that interpretability was important but not as important as accuracy, especially if the manager had access to someone skilled in tool operation.

3.2.2 Tool robustness (at specific spatial scales)

The robustness of water tools was often talked about in combination with the accuracy criterion. Many interviewees wanted tools at fine resolutions, but some acknowledged that this criterion could be difficult to achieve with a high level of accuracy. One federal agency representative thought that potential tool users should be more persistent in their pursuit of using and interpreting lower-resolution tools:

> A lot of people tend to fall on that crutch saying, "Well, it's not fine enough resolution for me to find useful." I think with a little bit of training and sort of a little bit of creative thought about how you use data that appears to be too coarse, you can certainly use it. [Federal Agency 5]

This interviewee was more optimistic about the use of coarser scaled data than many others while acknowledging that additional training may be necessary to make tools more widely usable.

Other interviewees, particularly state and NGO representatives, expressed a desire for finer-scale water tools, while also citing a desire to understand "the bigger picture" [State Agency 1]. In the following quote, an NGO representative described the connection between accuracy and spatial scale:

> I think accuracy is important for analytical, statistical modeling, or projection-style modeling. And there is a floor below which, if it's not accurate enough, then no one's going to feel comfortable communicating and using your outputs in a scientific sense. I think often accuracy does need to be smaller in spatial scale or higher accuracy comes at a smaller resolution. [NGO 4]

Others echoed this preference for finer resolution tools that align with the scale of management objectives, particularly smaller NGOs that focus on managing individual parcels of land.

3.2.3 Interpretability of tool outputs

Interviewees put a high value on the interpretability of water tools. Many federal agency representatives viewed difficult interpretation as a necessary challenge to "work through" for the sake of accuracy, as reported in the previous section. Still, federal agency representatives acknowledged that being able to understand a tool is crucial to its use:

> We know for certain that a tremendous body of information is not being used to the extent that it could be. It's really good to be able to develop these kinds of things, especially web-based mapping tools, but if you don't provide the opportunity for someone to understand how they can use it, and even sort of an example of where it's useful so the lightbulb goes on in their head…People could tell you something until you're blue in the face, but until you learn it for yourself, you're not necessarily bought in. [Federal Agency 5]

This interviewee's job was directly related to translating science to decision-makers, so they were very familiar with the usability criteria that encouraged tool use.

Many state and NGO representatives expressed the need for an accessible "expert" to explain water tools and how to use them in unique management contexts. One state employee thought it was important for someone familiar with a range of water tools to help colleagues determine the questions they want to answer before trying to interpret a tool's outputs:

> You talk to the manager about what their question is. You go back, you look at the science, you evaluate the science with the manager in the room saying, "Okay. So, here's all the different climate tools we have. What's your real question? How can we address…" And it might be that none of these tools, none of your drought tools really [answer] the question that they have. But we might be able to tweak them so that we can [answer] that question. [State Agency 1]

This interviewee held a unique role in their organization as, in their

Table 4
Usability criteria for water tools with examples of interpretation from interviews.

Criterion	Criterion Definition	Example of tool meeting criterion	Example of tool not meeting criterion
Accuracy	*Degree of agreement between estimated and actual conditions*	USDA EFH2 Estimating Runoff and Peak Discharge was deemed sufficiently accurate by a USFWS participant to guide water movement through water control structures to support habitat for birds.	The Drought Mitigation Center's Drought monitor was deemed insufficiently accurate by a Center for Large Landscape Conservation participant for scientific purposes such as using the data for models.
Robustness (scale)	*Resolution and site-specificity of the tool is appropriate for the management context*	The Nature Conservancy's Conserving Nature's Stage tool was deemed appropriate in scale by The Sagebrush Steppe Land Trust participant for individual property work.	BioClim variables from CliMond Climate Data were deemed insufficient in terms of appropriate scale by an IDFG participant for predicting species adaptation to climate change.
Extendibility	*Applicability of the tool over different physical conditions across a landscape, and over time.*	Intermountain West Joint Venture wetland dynamic modeling was deemed extendable over space and time by an IDFG participant for predicting wetland changes across the landscape and supporting wetland restoration efforts.	Climate Engine was deemed insufficient in terms of extendibility over time (not a high enough temporal resolution) by an IDFG interviewee for species habitat management and monitoring under climate change.
Interpretability	*Ease of understanding and incorporating tool into activities*	The Drought Mitigation Center's US Drought Monitor was deemed sufficiently interpretable by The Center for Large Landscape Conservation participant for agricultural risk management.	Drought Indices were deemed insufficiently interpretable by a Conservation Science Partners participant for meeting certain management goals.
Institutional fit	*Tool is appropriate given organizational goals and institutional context*	Tools created specifically for USFS by Rocky Mountain Research Station were deemed a good fit by a USFS participant.	METRIC Evapotranspiration Mapping Tool did not fit The Henry's Fork Foundation participant's needs for conservation practices evaluation and soil monitoring.
Capacity	*Organizational ability (e.g., funding, time, expertise) to use the tool*	The Utah State University Analytical Laboratories Walkley-Black organic matter test was deemed appropriate in terms of the Henry's Fork Foundation's organizational capacity to use the tool.	Haney Soil Test was deemed too expensive by the Henry's Fork Foundation participants for current capacity.

Acronyms: IDFG (Idaho Department of Fish and Game); USFS (United States Forest Service); USFWS (United States Fish and Wildlife Service).

words, the agency's "climate change person." They argued for the value of such a position in a state agency but acknowledged that it is rare, stating that "some other people in the surrounding states have filled that [tool expert] role in state agencies but I'm not sure if it's to the same degree that I do it" [State Agency 1]. NGO interviewees also described a need for access to "experts" [Land Trust 3] regarding water tool use and application in unique management contexts. We note that the suggestion to improve interpretability through access to an expert overlaps with the capacity criterion described below.

3.2.4 Institutional fit for a tool

Most interviewees described the importance of organizational goals and institutional contexts in deciding whether to use water tools. Interviewees talked about the difficulty of getting approval to use certain tools within their organizational hierarchy, particularly in federal and state agencies, and the lack of higher-level direction on tool use. This federal agency representative described the challenges associated with adopting new policy in government systems:

> I would say [the biggest barrier to using climate tools] would be vetting it through our national team. We have national discipline specialists who oversee evaluating tools to address resource concerns. So, you would need to have some sort of linkage to a resource concern and approval from whoever that discipline lead was to adopt that tool. And then there would be the other requirements for the way that the information is displayed to the public. [Federal Agency 2]

Because federal agencies may have lengthy processes for officially adopting new water tools, a particular tool might never be used, even if it were locally useful.

State agency interviewees also spoke to the importance of institutional fit in the following quote about short-term management priorities:

> As an agency, we're more driven by short-term goals. A lot of resources, or department resources, are focused on creating those short-term opportunities in the next few years. What are the opportunities that we're going to have available for our paying customers? [State Agency 2]

Because short-term goals were a priority in this particular state agency, some water tools were less likely to be used because of their focus on longer-term change.

While smaller NGO organizational structures tend to be more flat, some NGO representatives discussed the importance of "your board making [drought planning] a priority" [Land Trust 3] to enable tool use at a land manager level. This NGO employee gave an example of an organization-wide climate resilience plan that could not be implemented until the board declared "this is the priority" and gave permission to "set everything else aside" [Land Trust 3].

3.2.5 Capacity to use a tool

The need for "experts" to help interpret water tool outputs was sometimes associated with an underlying lack of organizational capacity to effectively understand and use certain tools. Capacity was defined in several ways by interviewees, including time, money, and expertise. Federal agency representatives described lack of capacity as resulting in the need for quick and easy-to-use tools that can help with day-to-day decision-making. For instance, one federal agency representative said, "we don't have time to sit down and think long-term, even if we want to" [Federal Agency 6]. State agency representatives added that lack of capacity was one of the major barriers to adopting tools that are not focused directly on short time frames.

NGO interviewees talked most about lack of capacity as a barrier to using water tools. These interviewees touched on all aspects of capacity including time, money, and expertise, as illustrated by the following quote:

> We're aware that there are tools out there and that we can use [them]. But to devote a staff member to potentially putting a year's salary into a conservation plan, it's just cost-prohibitive. [Land Trust 1]

Particularly in smaller NGOs, as this small land trust representative described, lack of capacity meant that it was even difficult to meet annual programmatic objectives, much less learn new tools.

4 Discussion

Decision-support tools can aid in landscape-level planning and fulfilling conservation goals in many systems (Bagstad et al., 2013; Keyantash and Dracup, 2004; Wardropper et al., 2021). While research has found multiple barriers to decision-support tool use for water and drought management (Brown et al., 2016; Núñez et al., 2014; Redmond, 2002), we identified many that are currently used in the US Northern Rockies region. While drought planning and climate resilience were rarely mentioned as organizational priorities by our participants, these goals often complemented short-term management actions.

Organizations across all three types (NGOs and state and federal agencies) relied most heavily on Data and Models to support decision-making. There were differences however across organization types associated with the second and third most used tool types, the most notable being very minimal adoption of Geospatial and Web-Based tools in federal agencies compared to a high level of adoption in NGOs, who utilized Geospatial and Web-Based tools second only to Data and Models. Our interviews suggest the lack of Geospatial and Web-Based tool utilization in federal agencies is due to many compounding factors which we have previously described in detail as usability criteria or barriers to adoption, with bureaucratic policy and procedures (Institutional fit) being one of the biggest challenges. Interestingly, state agencies were more active in adopting Geospatial and Web-Based tools when compared to federal agencies, which may suggest more flexibility in state policy and procedures regarding adoption of more advanced decision-making tools.

Two crucial challenges to tool use were lack of capacity for long-term management using tools and lack of fit between a particular tool and institutional objectives. Institutional fit is an important but understudied factor in natural resources organizations' management processes (Guerrero et al., 2021). In the case of water tools, interviewees pointed to situations in which higher-level decision-makers in their organizations did not support the use of particular tools because of conflicting programmatic objectives or contractual issues. Other issues relating to the interpretability, robustness, and accuracy of a tool also posed usability challenges. For example, within discussions of tool interpretation, interviewees voiced the need for an expert role to help inform the use and application of tools, bridging the gap between researchers and managers as discussed in Sunderland et al. (2009). Furthermore, interviewees described the overwhelming abundance of tools, which created a cognitive burden when deciding which tool to use for a particular decision.

There is a need for increased collaboration between tool producers and managers to better inform tool development and use, increasing adaptive capacity, and achieving sustainable outcomes (Prokopy et al., 2013; Schwartz et al., 2018; Sunderland et al., 2009). Co-production has been proposed as an effective way to increase adaptive capacity goals for organizations or systems (Bremer and Meisch, 2017). Co-production, a process through which individuals from different organizations, backgrounds, or epistemologies work together to develop processes and outputs (Ostrom, 1996), may provide opportunities for tool users and developers to work together to improve tool usability and incorporate into sustainability decisions. Co-production can provide opportunities for tool users and developers to discuss the costs and benefits of, for instance using different variables in tool outputs and tradeoffs between accuracy and scale, and explore observations from both Western scientific and local knowledge (Mbah et al., 2021; Vincent et al., 2018). Importantly, co-producers of a decision-support tool may need to allocate additional time to make the process inclusive, collaborative, and flexible (Vincent et al., 2020). A boundary organization, whose role is to mediate between scientists and users of scientific outputs (Guston, 2001), could help coordinate collaborations to address some of the usability concerns expressed in our interviews.

Our results are intended to improve understanding of how staff in landscape management organizations use water tools, and what criteria staff use in determining whether to use a tool. One shortcoming of the data collection in this study is that we had unequal representation across different organization types – a disproportionate number of our interviewees were from NGOs. This overrepresentation of NGOs may be one reason why capacity came up so often as a barrier to tool use, as these organizations often work on shoestring budgets. That said, as governmental budgets have shrunk over the past several decades in the U.S., low capacity is a problem faced by governmental and non-governmental organizations alike. We also only spoke with staff in organizations for this study—we did not include individual land managers or owners because this potential user group has very different needs with respect to water tools (Wardropper et al., 2021). While there have been a few recent studies on rancher and pastoralists' use of decision-support tools (Coppock, 2020; Machado et al., 2020) more detail is needed to improve tools for this group.

5. Conclusion

As climate change threatens the provision of hydrologic ecosystem services worldwide, managers are forced to make decisions under increasing complexity. The US West is already experiencing a new climate "normal" of increased dry weather, including more frequent and severe drought (NOAA, 2021b). Improved decision tools can aid in day-to-day and longer-term decisions such as drought declarations. This study provided qualitative data on the process of decision-support tool use with the applied aim of addressing a disconnect between managers and researchers in natural science fields in our study region and beyond. Through interviews and qualitative analysis, we identified a wide variety of water tools currently used by staff of governmental and non-governmental landscape conservation organizations and provided six criteria our research participants use when deciding whether a tool is appropriate for certain decisions. These criteria can be used by both tool creators—to assess potential needs and capacity of target users—and user organizations—to understand which tools are best for the organization's goals and what employees might need to better utilize those tools. Future qualitative research could further expand our understanding of how decision-support tools fit organizational goals and whether co-production might improve this fit.

6. Data availability statement

The sociological data used in this study are available – without identifying information – by request from the authors.

CRediT authorship contribution statement

Lily Fanok: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Project administration, Funding acquisition. **Bray J. Beltrán:** Conceptualization, Validation, Formal analysis, Writing – review & editing, Supervision. **Morey Burnham:** Conceptualization, Methodology, Validation, Resources, Writing – review & editing, Supervision. **Chloe B. Wardropper:** Conceptualization, Methodology, Validation, Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jhydrol.2022.127531.

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