

CHAPTER 11

Navigating scales of knowledge and decision-making in the Intermountain West: implications for science policy

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11.1 Introduction

Defined simply as the “spatial, temporal, quantitative, or analytical dimensions used to measure and study any phenomenon,” [1] scale is a key analytical and explanatory attribute of the human–environment system [2]. Considerations of scale are fundamental to investigating and understanding how to support research, outreach, and engagement with decision-makers who need useful information to expand policy alternatives, clarify choices, and otherwise improve policy outcomes [3]. Unfortunately, navigating across multiple scales of research and decision-making is a difficult task for many traditional research entities, and failure to actively manage multiscale challenges can lead to the production of information that is not useful for decision support.

In this chapter, we illustrate how the Western Water Assessment (WWA) has identified and addressed problems of scale in order to support climate-sensitive decision-making by water resource managers in the Intermountain West. One of the oldest Regional Integrated Sciences and Assessments (RISA) programs, WWA began in 1998 as an initiative among scientists

at the University of Colorado's Cooperative Institute for Research in Environmental Sciences and the National Oceanic and Atmospheric Administration's (NOAA) Climate Diagnostics Center. WWA has since evolved into a full-fledged RISA working in Colorado, Wyoming, and Utah, a region characterized largely by semi-arid grasslands, high-elevation mountain ranges, and desert basins. WWA's mission is to "conduct innovative research and engagement aimed at effectively and efficiently incorporating knowledge into decision making in order to advance the ability of regional and national entities to manage climate impacts." Given the water scarcity in the region, WWA's primary focus has been on the water sector.

Much has been written about the concept of scale and how it is used across the natural and social sciences, especially when examining how science can better inform efforts to govern in the face of environmental change [1,4,5]. Scholars have focused on improving the precision with which we understand and use scalar concepts (e.g., temporal, spatial, jurisdictional, institutional; see [6]) and levels within scales (e.g., daily/seasonal/annual, or local/state/national.) The concept of "mismatches" or lack of "fit" among levels of spatial scale such as watersheds, levels of jurisdictional scale of governance such as state boundaries, and levels of institutional scale such as regulatory rules is well recognized (e.g., [1,6]). Challenges have also been identified in connecting the spatial validity of data for a given level of application and the needs of decision-makers at particular jurisdictional levels (e.g., applying global models to local resource decisions) [4,7]. In this chapter, we draw on these concepts but do not attempt to capture the scale discussion in its entirety. Instead, we focus on examples from WWA's experience that illustrate how scale and level considerations influence the production and application of knowledge in decision-making. With particular reference to knowledge, we examine who produces the knowledge, at what organizational level, and with what spatial characteristics relevant to the level of jurisdiction and decision-maker.

As a RISA, WWA provides an ideal opportunity to ask these questions and observe the challenges of knowledge production and use across spatial levels and jurisdictional boundaries. The geographic and jurisdictional levels of operation of RISAs are deliberately cross-cutting and loosely defined, giving them the freedom to seek out knowledge and knowledge producers from a variety of spatial and institutional levels in order to connect with decision-makers at multiple levels within a region. Rather than acting as a constraint, a regional focus provides scale-dependent advantages, allowing RISAs to experiment with new sources of knowledge, connecting decision-makers with previously unfamiliar knowledge providers or expanding the scope of knowledge provision to new types of decision spaces. The guiding principle for RISA work is to begin with the decision context of

particular stakeholders in a region and to let that context shape the sources and types of knowledge that are brought to bear on decision-making. Moreover, RISAs have been able to interact with actors at multiple scales from both sides of the science–policy boundary because they are free from the strictures of official government-provided climate services and because they are still able to maintain longstanding relationships with researchers and decision-makers. This also enables RISAs like WWA to be nimble, flexible, and experimental in order to adapt to changing scientific and policy windows of opportunity.

Intertwined with considerations of scale are additional research findings demonstrating that decision-makers are more likely to use scientific information if it is considered to be salient, credible, and legitimate [8,9]. *Salient* information is inherently sensitive to context and relevant to the particular spatial, temporal, jurisdictional, and institutional scales of a problem. For example, climate information developed and presented at a national level of spatial scale can be so broad that it may not apply well to local-level decisions. Whether or not information is *credible* relates to users' perceptions of accuracy and quality of the data or perceptions about the standing of the knowledge producer. Users also view information as *legitimate* when they believe it was produced free from political persuasion or bias and when their needs and concerns were somehow incorporated into that production process. Finally, useful information takes on a procedural dimension in which producers and users of information engage in a dialogue aimed at shaping research agendas based on the context and scale-dependent needs of decision-makers [10,11]. In our experience, producing usable and salient information for decision support means that we must consider how to navigate multiple spatial levels and dimensions, but also ensure that WWA produces high-quality information and is viewed by decision-makers as a trustworthy source of knowledge.

In this chapter, we show how WWA has engaged in this process of “navigation” to make climate knowledge, produced at multiple spatial and temporal levels, useful in supporting public decision-making at multiple jurisdictional levels. The WWA experience demonstrates some of the challenges facing this process, such as identifying information relevant to a particular decision context and providers capable of creating and/or delivering such information; navigating scales to provide salient, credible, and legitimate knowledge for particular contexts; and addressing the unfamiliarity or lack of trust between relevant knowledge providers and decision-makers who each have relevant contributions to the problem.

We draw from existing literature and theories to demonstrate these scale challenges and then share five case studies from WWA's work in order to explore how strategies of convening, translating, collaborating,

and mediating, commonly used in boundary work, can help navigate scale-dependent problems. We conclude with a discussion about science policies needed to support climate research aimed at decision support. Specifically, we argue that science policies need to be changed in order to ensure that grants are of adequate duration to support building and sustaining relationships, that research organizations are nimble and flexible enough to respond to emerging opportunities, and that boundary work is adequately evaluated and incentivized by funding agencies, universities, and other research facilities.

11.2 Doing boundary work to overcome scale challenges

Decision-makers need climate information that is salient, credible, and legitimate to help inform decisions related to climate adaptation. When called upon to respond to specific information needs, however, traditional science producers often provide information developed to answer scientific questions rather than information intended to be useful in specific decision contexts. Moreover, science producers are often unaware of common scale-related problems (see Table 11.1) that challenge the effective integration of climate information into decision-making [3,4]. Producing usable information requires that the work of scientists and the needs of decision-makers be reconciled through increased interaction between both groups. There are pitfalls in this process, however—too much involvement of science in policy decisions can lead to the politicization of science and reduced credibility, while insufficient interaction may result in the production of more information without improving usefulness.

Striking the right balance, therefore, requires “boundary work” to actively manage the boundary between science and policy [12]. Boundary work involves four key strategies: *convening* different actors to produce useful information, *translating* information to actors on both sides of the science–policy divide, providing opportunities for *collaboration* in research or product development, and *mediating* problem framing and conflict among actors [12,13]. This work is carried out by boundary organizations [12] whose function is to straddle the boundary between science and policy and strive to increase linkages between science and policy while simultaneously working to preserve scientific credibility. When done effectively, boundary work can increase the usefulness of climate information in scale-dependent contexts [4]. WWA and other RISA programs have often been described as “boundary organizations,” meaning that they are entities specializing

Table 11.1 Major scale discordance problems affecting societal responses to climate-related challenges.

Scale challenge	Definition
Institutional fit problem	Mismatches between the spatial scale of environmental phenomena and the geographic scale of political entities (e.g., counties, cities, or states).
Scale discordance problem	Mismatches occurring when available scientific information does not reflect the unique context of the environmental conditions and/or the geographic scale of decision-making; often arises in trying to apply general research findings to specific contexts or when efforts to assess climate impacts are conducted at scales not relevant to decision-making.
Insufficient attention to cross-scale linkages	Mismatches related to an over-reliance on scientific causal explanations at one particular scale at the expense of identifying other causal relationships at different scales; often arises when scientists undertake research aimed at a single scale of decision-making and miss cross-scale interactions that affect decision contexts.

Source: from [4].

in boundary work [14] and thus provide ideal opportunities to examine the value of such organizations in navigating scales to provide climate information for decision support.

This chapter uses case studies of specific WWA processes or outputs to illustrate the efforts involved in such boundary work. The examples provided in the following text all demonstrate the multiple scales and levels of scales at issue in a given context, one or more climate-related scale challenges, the use of boundary work strategies in meeting scale-related challenges, and lessons learned from addressing relevant scale challenges. Figure 11.1 provides a visual demonstration of how each of the cases crossed multiple levels of knowledge production and decision-making.

11.2.1 Reservoir management and endangered species workshop

In 1995, the NOAA Climate Prediction Center (CPC) began issuing a new generation of seasonal predictions based on the El Niño-Southern Oscillation (ENSO) climate phenomenon. WWA took advantage of these predictions for its first major event, a 1999 workshop that brought together WWA partners, potential stakeholders, WWA researchers, and water managers. The assembled group identified a potential area of collaboration to explore

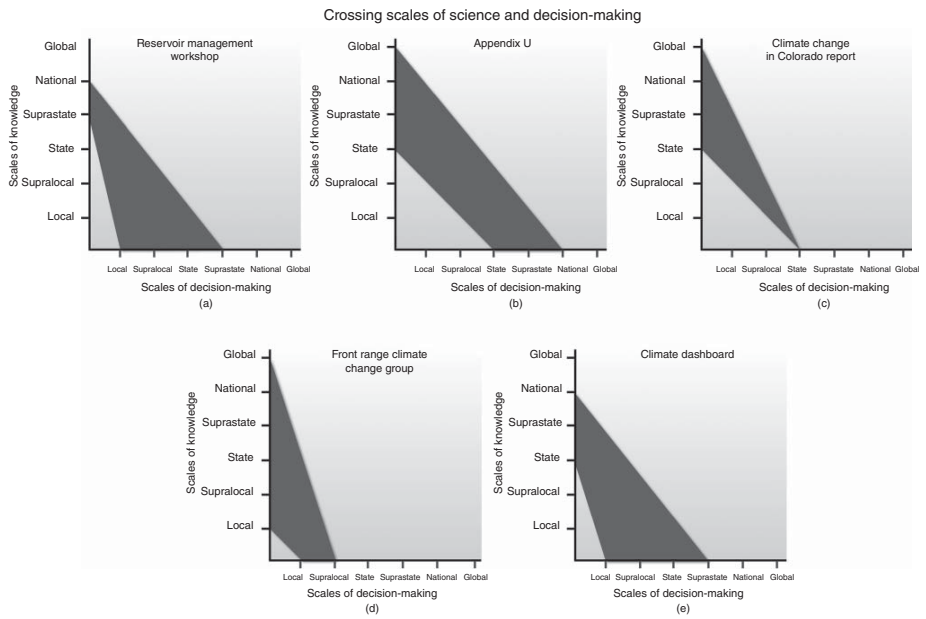


Figure 11.1 (a)–(e) Individual examples of how WWA’s work crossed multiple scales. On the y-axis are scales of knowledge shown at the level of the climate knowledge producer, while the x-axis shows scales of decision-making. “Supralocal” refers to decision-making or knowledge production entities that operate at a scale greater than an individual municipality but less than an entire state, while “suprastate” refers to entities operating at scales larger than an individual state but less than national.

the benefits of applying these seasonal predictions to water supplies on the Upper Colorado River in Colorado. That fall, WWA and two important stakeholders in reservoir management, the Colorado River Water Conservation District (CRWCD) and Denver Water, co-convened the “Workshop on Weather and Climate, Reservoir Operations, and Endangered Fish in the Upper Colorado River Basin.” This workshop was designed to provide an opportunity for NOAA, university scientists, and other climate information providers to discuss available ENSO-related research and products. In turn, water resources decision-makers informed researchers about reservoir operations, the challenge of meeting flow requirements for endangered fish, and whether current climate information could be used in planning. Overall, the workshop attempted to bring the understanding of ENSO impacts and seasonal predictions from NOAA’s national seasonal climate outlooks to the context of decision-making for water resources in the Colorado River headwaters region. (Note: This workshop is discussed further in Chapter 2.)

The institutional and jurisdictional levels at issue here illustrate the complexity of the decision-making context (Figure 11.1(a)). Water management stakeholders involved in the workshop included a federal agency (the U.S. Bureau of Reclamation, hereafter “Reclamation”), two supralocal entities (the CRWCD and the Northern Colorado Water Conservancy District), and a local-level water utility (Denver Water) whose operations span two water basins, with its service territory located in the South Platte Basin but with significant additional supplies and storage capacity in the Colorado River headwaters area. The US Fish and Wildlife Service was also present because of their mandate to restore habitat for endangered fish downstream on the Colorado River. This mandate was challenging managers at multiple spatial and institutional scales to come up with a strategy to provide water for fish under the federal Endangered Species Act. Thus, water management in this basin was at a point of criticality and at a nexus of local, state, suprastate, and federal levels of jurisdictional and institutional scales. Knowledge, meanwhile, was being produced at a regionally relevant level by national research institutions. Throughout this process, WWA faced the dual task of helping users see that knowledge as salient, credible, and legitimate, while also providing feedback to NOAA on improving its usability. Over the next several years, WWA funded studies to both understand the user context (described in [15] and Chapter 2) and to facilitate the use of National Weather Service 8–14 day outlooks and NOAA CPC seasonal outlooks in river management [16]. WWA also regularly engaged with both the CPC and the NOAA Colorado Basin River Forecast Center to improve the usability of their products.

Crossing multiple levels along these multiple scales raised a number of challenges. The first arose from the fact that seasonal predictions of temperature and precipitation related to ENSO were not being incorporated into NOAA's streamflow forecasts for the Colorado River Basin. WWA scientists also were concerned about the level of skill involved in the seasonal predictions and about ensuring that the managers understood that skill. Thus, the workshop intended to discover if more skillful forecasts might have a place in reservoir management and what temporal and spatial levels of forecasts would be most salient. The complex nature of reservoir operations conducted by a variety of entities operating under different sets of rules and practical constraints led to a cross-scale concern; without an understanding of the myriad interconnections among the entities involved, including who influenced decisions, efforts to bring climate information to bear would be of limited value.

To address these problems, WWA used multiple boundary work strategies. First, it served a convening function, providing an opportunity for knowledge producers and decision-makers across scales and levels to collaboratively explore the potential uses of climate knowledge such as seasonal climate and streamflow predictions, a process that was ongoing for several years. This procedural dimension—engaging over time—is described in Lemos and Morehouse [17] as part of the “iterativity” required to produce usable information. Scale issues were also addressed through translation by providing explanations of the skill of the prediction products in a form accessible to water managers who were technically savvy professionals, not trained in climate science. WWA also sought to provide climate information that might expand the range of choices and options for reservoir managers, potentially expanding the range of possible options for meeting ESA requirements for environmental flows. We consider this to be a type of *mediating* function—providing information that might reduce the potential for conflict among water managers.

Internally, WWA saw the workshop to be an early success because many of the water management entities represented became active partners in WWA's future work, relationships that have been sustained through to the present. Thus, WWA's use of boundary work strategies allowed it to progress from initial relationship building through the workshop to the collaborative production of research and then to a position as an expert voice on interpreting information regarding climate change.

11.2.2 Appendix U

The Colorado River provides critical water supplies to seven states under a complicated set of rules defined by the Colorado River Compact. Prior to

2005, no plan existed for managing the river's two major reservoirs (Lakes Powell and Mead) during a drought of magnitude sufficient to prompt the states in the Lower Basin to "call" for water from the Upper Basin. In light of an unprecedented drought during the 2000s, however, Reclamation began a process of developing new operating criteria for the two reservoirs, ultimately resulting in the "Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations of Lake Powell and Lake Mead" [18]. WWA, which had a working relationship with Reclamation's Upper and Lower Colorado River regional offices since the late 1990s, provided leadership and guidance as part of the Climate Change Technical Work Group (TWG) that produced "Appendix U," a detailed assessment of the impacts of climate change on future flows in the Colorado River. Appendix U was included as part of the final Environmental Impact Statement (EIS) for the new drought management criteria.

As shown in Figure 11.1(b), the development of Appendix U involved a wide variety of knowledge and decision-making levels. The primary level of decision-making involved a federal agency (Reclamation) that was engaged in a formal environmental impact analysis as required by law for a decision of such magnitude. However, the geographic scale of the EIS itself was suprastate—involving the Colorado River Basin—and strongly tied to decision making and planning at the state level, given that seven states are party to the Colorado River Compact. On the other hand, knowledge used in the report was generally generated at higher levels, such as global climate models and the suprastate-scale Colorado River Simulation System model used by the TWG to translate climate projections into future hydrology scenarios.

For WWA, the major scale challenge in this case was an institutional fit problem—the climate knowledge needed for this effort was scattered among many science institutions and produced at a variety of levels, not all of which were directly relevant to assessing projections of future flow in the Colorado River. Research institutions rarely possess the in-house capacity to quickly adapt their knowledge to the spatial levels needed for the decision context. In addition, this case also illustrates a temporal institutional fit problem—Reclamation needed climate information provided in significantly less time than would normally be possible under traditional research time frames.

To address these problems, WWA worked with Reclamation and other RISAs to convene the TWG, which included experts in meteorology, climate, and hydrology from WWA, other RISAs, NOAA, the U.S. Geological Survey, and a consulting firm. Once convened, the TWG collaborated with Reclamation to produce relevant information by convening multiple research groups to frame and synthesize appropriate climate knowledge. The TWG was able

to bring to bear science on two temporal levels not previously reflected in Reclamation's analyses—paleoclimate information to reflect conditions out of the range of the historic record and projections of future climate change. Meeting the temporal challenge (the work needed to be done in less than a year to meet the needs of the EIS process) required WWA to harness its scale-dependent advantages, helping the TWG synthesize information and produce new knowledge in a time-frame rarely seen in traditional research. This effort also demonstrated the value of translation as a strategy for incorporating climate science into a document relevant to the work of water resources engineers.

The funding flexibility provided by the RISA program gives WWA the ability to allocate resources based on emerging problems. In this case, WWA was able to successfully facilitate the work of the TWG—including funding its scientists to participate—in developing climate information to meet a “policy window” [19] that would be too short for a typical research grant to respond. Collaborative efforts undertaken for Appendix U also led to the development of a separate multi-stakeholder project that evaluated and synthesized existing research on future warming impacts and projections for overall flow in the Colorado River [20]. Through these efforts, the group was able to integrate the research developed at multiple spatial and institutional levels to provide information that was more useful and directed to the interests of Colorado River stakeholders than any single effort could have independently accomplished.

11.2.3 Climate Change in Colorado

In 2007, Colorado Governor Bill Ritter issued a Climate Change Action Plan for the state that called for state agencies to “prepare the state to adapt to those climate changes that cannot be avoided” [21]. After that plan was issued, the Colorado Water Conservation Board (CWCB, the state agency charged with long-term planning and management of water resources) commissioned WWA to help compile relevant climate science into a report oriented toward the water resources sector. WWA had been interacting with the CWCB since the 1999 workshop described earlier, so the idea for such a project came out of ongoing discussions. The resulting report, *Climate Change in Colorado* [22], was collaboratively produced by WWA and the CWCB, with inputs from other water management entities across the state. It provided a synthesis of the existing climate observations and projections as well as research on understanding potential changes to surface water supplies under a warming climate.

As shown in Figure 11.1(c), a variety of spatial levels of knowledge production were brought to bear on the development of this report, which was

in turn oriented toward decision-making at a specific set of jurisdictional levels. The report authors drew from global-level research (e.g., global climate model projections), suprastate-level research such as climate change impacts to flow in the Colorado River, and state-level information such as observed records of the state's climate. CWCB wanted a product that would inform state-level decision-making, although it was also useful for water management within larger entities like Reclamation and smaller entities like Denver Water.

Climate Change in Colorado primarily sought to address a scale discordance problem between knowledge produced at global spatial and institutional levels and decision contexts at the state and local jurisdictional levels. At the time, a number of scientific assessments of climate change impacts had been produced—notably the IPCC Fourth Assessment Report (AR4) [23]; policymakers in Colorado were interested in understanding more precisely how this information was relevant to water management in the state. AR4 was produced at a global scale, providing at best continental-scale analyses and information oriented toward national and international decision-making. CWCB needed information oriented toward state-level decision-making, which prior to creation of *Climate Change in Colorado* had either not existed or not been readily available. Thus, the challenge in developing the report was to translate knowledge produced at global, suprastate, and state scales into a form sufficient for supporting state-level decision-making.

To solve this scale discordance problem, WWA relied primarily on translation and convening strategies. The translation strategy was employed not simply by synthesizing global and federally produced climate information for the state and supralocal levels, but also by crafting a report that was relatively free of scientific jargon and was comprehensible to decision-makers. In addition, WWA and CWCB both provided funding and leadership that enabled the convening of scientists from multiple entities, including NOAA's Physical Sciences Division, the University of Colorado Boulder, and Colorado State University. A number of water management agencies (listed as contributors in that report) collaborated by participating in meetings to study the scope and design and review the report. WWA was able to harness its ability to operate at the right jurisdictional and spatial levels while coordinating among entities with overlapping. The report underwent a rigorous review process, which included reviewers from both sides of the science-policy divide, giving it legitimacy in the scientific and decision-making worlds. The result was a co-branded report that provided useful, decision-relevant summaries of climate observations and projections for the state. As a measure of its usability and relevance, the report has been used repeatedly by

the CWCB to demonstrate the need to account for climate change in future water supply planning. In addition, the CWCB requested an updated version of the report subsequent to the release of new global climate modeling efforts [24].

11.2.4 Front Range Climate Change Group

As described in [25], municipal and industrial water utilities (M&Is) along Colorado's Front Range urban corridor evolved from only considering seasonal climate information in operations to actively examining potential climate change impacts on supplies and integrating those impacts into planning efforts. Building on its previous collaborations with Front Range water providers, in 2006 WWA provided a workshop on climate change and potential impacts on Front Range water supplies, followed by a 2008 workshop on climate modeling. The utilities interested in the process then began an affiliation known as the Front Range Climate Change Group (FRCCG). In collaboration with WWA, the FRCCG worked with a consulting group to conduct a formal study (called "The Joint Front Range Climate Change Vulnerability Study") to examine the vulnerability of their shared water-supply resources. In 2013, WWA began working with the FRCCG to provide a series of continuing educational workshops on climate-related issues.

Figure 11.1(d) demonstrates that WWA's work with the FRCCG is mostly relevant to local decision-making, particularly planning and operations at M&Is. However, the FRCCG is also a supralocal entity—in other words, a group of local entities that consider the effects on resources they share at spatial and jurisdictional levels greater than their own individual service boundaries. As is common with many of these efforts, climate knowledge generated at multiple spatial levels was brought to bear on the FRCCG—from global climate model output to supralocal streamflow data from the Colorado Decision Support System to localized knowledge about vulnerabilities to a watershed or particular provider.

Similarly to the *Climate Change in Colorado* example, the FRCCG's activities were subject to institutional fit and scale discordance problems. The M&Is engaged in a joint effort largely because they use supply sources located well beyond the boundaries where they deliver water. Moreover, some of these utilities were looking at the same water sources to provide additional supplies as buffers against climate change-related decreases in supply. To provide information that would help making more informed decisions in the face of these problems, the group needed climate science produced at multiple levels in order to develop information relevant to decision-making in the Front Range context.

More importantly, perhaps, an institutional fit problem arose from the nature of the entities collaborating on the development of the study. Many science entities that develop climate-projection information are accustomed to working on longer time frames through a traditional grant-research model, whereas the M&Is are accustomed to rapid scoping and development of projects, primarily working through a consultant-client model. To deal with that hurdle, the FRCCG used a consulting company as the technical authors of the study but enlisted WWA and other scientific experts in the scoping and review of the project. WWA helped move this process along using convening and collaborating strategies, but it is important to note that FRCCG members themselves led the effort, not WWA. In its continuing role in facilitating climate literacy improvements through a translation strategy, however, WWA has worked on an ongoing basis to provide further workshops and other materials to help the group stay abreast of emerging climate-related issues.

WWA's interactions with the FRCCG relied on boundary work to help facilitate the process of bringing together experts and stakeholders to develop shared knowledge about climate change in a specific context. Particularly critical to this success was the ability of WWA to participate in rapidly developed efforts aimed at understanding the utilities' common vulnerabilities. In this instance, although the FRCCG members were more accustomed to working directly with consulting companies to produce reports, WWA was key enough to the overall effort that one of the members of the FRCCG referred to WWA as "the most effective and beneficial model for meeting our education and assessment needs" [26].

11.2.5 Intermountain West Climate Dashboard

Since 2005, WWA has produced a climate summary oriented toward water and other resource decision-makers in its three-state region. Initially, WWA sent out a monthly "Intermountain West Climate Summary" (IWCS; modeled after the "Southwest Climate Outlook" created by the Climate Assessment for the Southwest RISA) providing graphics and recent climate conditions and seasonal forecasts accompanied by a narrative explanatory text. IWCS issues frequently included articles aimed at improving readers' climate literacy or introducing new WWA work. The IWCS primarily served as a single point of reference for multiple sources of information developed at a variety of spatial and institutional levels of knowledge production. In 2012, WWA replaced the IWCS with a dashboard-style website, the Intermountain West Climate Dashboard (IWCD), which provides real-time versions of the same information using more advanced web technology along with short explanatory text updates.

The IWCD is perhaps the broadest cross-scale interaction WWA engages in (see Figure 11.1(e)), largely because of the variety of producers and the number of entities interested in similar information. The primary users of the dashboard (based on a list of approximately 500 email subscribers) include entities at virtually all jurisdictional levels, from local (e.g., individual M&Is) to suprastate/national (e.g., Reclamation). Information displayed on the website includes products produced primarily at the national (e.g., seasonal forecasts from NOAA's CPC) and suprastate (e.g., precipitation maps from the High Plains Regional Climate Center) levels by climate service institutions that generate much of the climate information available in the United States.

Alone, these products are often not matched well to the information needs of many decision-makers. Collectively, however, having the IWCD as a single point of reference allows decision-makers to assimilate information from a variety of scales for their purposes. The IWCD tackles the problem of integrating information from multiple scales by gathering information from diverse sources through a web-based tool, resulting in the production of a useful cross-scale product that cannot otherwise be created by individual climate information producers.

The IWCD (and its predecessor, the IWCS) has successfully played two roles in crossing scales—first, by translating a variety of climate information products available from diverse and often uncoordinated sources into formats more easily used by subscribers; and second, as a means to draw stakeholders' attention to WWA's work by creating a subscriber list that receives other updates on WWA's work. A 2008 survey done by WWA demonstrated that a core group of IWCS subscribers found the summary to be an efficient way to access important climate information. Although no similar survey has been conducted for the IWCD, initial feedback from specific users indicated that the new format provided the same information in a more efficient manner. Moreover, imitation may be a measure of success—the IWCD has already been replicated by other climate service organizations, including the Colorado Climate Center.

11.3 Implications for science policy

Our aim in this chapter has been to demonstrate how WWA's use of boundary work and its structural flexibility helped to bridge climate knowledge production and decision-making across multiple scales. These efforts stand in stark contrast to the bulk of climate-related research, which is aimed at expanding our general understanding of climate phenomena by testing hypotheses and informing various theories. Most climate research

also generally focuses on large-scale processes that are rarely relevant to decision-makers without extensive translation.

Transforming climate research, along with other climate information not produced in the context of user needs, into forms useful for decision-makers requires boundary work, particularly when attempting to navigate the kind of scale-related challenges we have identified in this chapter. Unfortunately, existing science policies and basic research structures often do not support boundary work and even create disincentives for doing it. Producing usable information will thus require shifting science policy and funding to better support boundary work in research organizations. Specifically, science funding entities should consider offering more grants that are of adequate duration to support building and sustaining relationships. Research organizations should aim to be nimble and flexible in order to respond to emerging problems, and boundary work should be adequately evaluated and incentivized by funding agencies, universities, and research facilities.

These shifts in science policy are critical for orienting climate knowledge production to decision support, as demonstrated not only by WWA's experience but also by the lessons learned in a variety of other contexts (e.g., [9, 10]). For example, convening diverse groups of decision-makers and researchers is predicated on relationships based on mutual trust and respect, which takes resources and time to accomplish. The ability to convene decision-makers and researchers enables boundary organizations like WWA to better assess users' information needs, tailor research to respond to those needs, understand the context in which climate science will be used, connect different actors to each other, and efficiently use resources to conduct, communicate, and translate research. Convening researchers was particularly important in WWA's work on the Climate Change in Colorado Report, as well as with the FRCCG. Moreover, time spent building relationships in one instance—such as during the Reservoir Management and Endangered Species Workshop—yielded future benefits when established relationships were leveraged in emerging projects. WWA's experience suggests that this sort of convening may take years of cultivating relationships before they can be leveraged for successful outcomes. Typical grant funding cycles, however, last between 1 and 5 years, which may not be enough time to build relationships and carry out boundary work to produce usable information. Science policies aimed at producing usable information for decision support should therefore be structured to allow more time to build relationships, particularly in the early stages of the funding cycle when convening work is just getting underway. Providing funding support from 5 to 10 years may be more appropriate for boundary work especially in contexts where societal problems are culturally, politically, or scientifically complicated.

Developing long-term relationships with stakeholders is also critical to enabling boundary organizations to be ready to respond to emerging problems in order to produce useful information. WWA's experience with Appendix U demonstrated its ability to take advantage of a policy window by convening diverse groups of researchers, collaborating on research, and producing a report in a single year. This was due to the program's organizational design, enabling it to reallocate human and financial capital to take advantage of emerging opportunities. WWA has the discretion to apply a sizeable portion of its budget on projects that it does not have to identify in its initial grant proposal, enabling it to be flexible and nimble in shaping its research agendas. In contrast, most federally-funded researchers are required to explain their entire budget in detail, locking in research agendas before they have received any funding or adequately assessed users' information needs. RISA programs are given more latitude to make decisions about how to spend their money during their funding period, allowing them to be more entrepreneurial, thereby shaping their research to best respond to emerging opportunities. Other research efforts aimed at producing usable information for decision support could learn from this model by providing more discretion in allocating funds and shaping research agendas during funding periods.

Reconsidering traditional research incentives could also help support efforts to make climate information usable. Boundary work such as convening, translating, collaborating, and mediating is rarely rewarded in the basic research community, in universities, or at federal research facilities; yet it is critically important in producing usable climate information for decision support. One of WWA's most widely used products, the IWCD, is largely a translational effort. The Reservoir Management and Endangered Species Workshop and the Climate Change in Colorado Report both depended on strong convening and mediation efforts by WWA. Such boundary work, however, results in outputs and outcomes that may be ambiguous and difficult to quantify, especially when compared to the standard peer-reviewed publications used to evaluate most research. Doing this type of work is not only difficult to evaluate, but disincentives at most research institutions often make researchers reluctant to participate. For example, tenure, retention, and promotion decisions at universities are largely based on the number and quality of one's peer-reviewed publications, forcing early career researchers to weigh the possibility that their efforts at boundary work may not only be missed in the evaluation process, but may also be seen as an unnecessary distraction to doing research that results in peer-reviewed publications. Science policies need to consider the development of incentives and evaluation that properly reward boundary work [9]. Research

grants need to be explicit about supporting boundary work and ensure that such work will be considered in evaluating the success of the research program. Moreover, universities and research facilities that are interested in supporting use-inspired research need to expand their criteria of what constitutes worthwhile activities when evaluating tenure, retention, and promotion.

11.4 Conclusions

Multiple challenges face research organizations that work across the boundary of science and policy and strive to produce and deliver usable climate information that expands alternatives, clarifies choices, and enhances capacity to adapt to a changing climate. Over the past decade and more, the loose definition of being a “regional” entity has been used for WWA to overcome many of these challenges. Other scale-dependent advantages include being able to draw from a variety of knowledge sources produced at multiple institutional and jurisdictional levels while also interacting credibly in decision contexts at multiple levels. WWA’s role as an autonomous research organization allows it to convene researchers, decision-makers, and other stakeholders from national to local levels and across sectors. This in turn facilitates building collaborative relationships with knowledge producers from diverse disciplinary, geographic, and agency affiliations, translating complex scientific information into salient and useful formats, and providing information about climate risk in appropriate policy contexts. While WWA rarely engages in direct mediation efforts among conflicting parties, its ability to provide information that expands policy options has helped ameliorate some water resources conflicts in the Intermountain West.

Ultimately, however, the ability of WWA and other RISAs to succeed in their efforts to navigate across scales and provide climate information relevant to decision support is hampered by a variety of science policy constraints that have been just described. Despite the U.S. Global Change Research Program’s new strategic plan calling for more use-inspired research, any substantive changes are yet to be seen, which would support more RISA-like research. Science policies have been slow to support the growing need for usable climate information, echoing earlier criticisms made about the program [11,27–29]. Conducting basic research aimed at contributing to our fundamental knowledge about climate change will always play a critical role in climate science. Use-inspired research, however, does not drive out basic research, so it is not an “either/or” dilemma. As we demonstrated in our cases (and in other research; e.g., [14]), directing

research toward producing usable information for decision support can achieve multiple goals simultaneously: it can address scale-dependent challenges, produce information that is salient, credible and legitimate, and contribute fundamental knowledge about climate science.

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