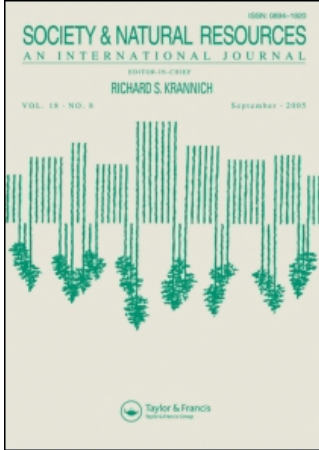


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Water Managers' Perceptions of the Science–Policy Interface in Phoenix, Arizona: Implications for an Emerging Boundary Organization

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A potential water supply crisis has sparked concern among policymakers, water managers, and academic scientists in Phoenix, AZ. The availability of water resources is linked to population growth, increasing demand, static supply, land use change, and uncertainty. This article examines the perceptions of water managers working at the science–policy interface in Phoenix and discusses the implications of their experiences for the development of an emerging boundary organization: the Decision Center for a Desert City. Qualitative analysis of data generated through in-depth interviews with water managers uncovers two understandings of the intersection of science and policy: One perspective is a traditional, linear model with sharp conceptual distinctions between the two spheres, and the other is a recursive model recognizing fluid boundaries. Managers describe uncertainty as inescapable, but manageable. A prescriptive model for the science–policy interface for Phoenix water management is presented.

Keywords climate change, drought, environmental policy, uncertainty, urban water resources, Western water management

According to the U.S. Bureau of Reclamation (2003), Arizona is at the center of a geographic region facing a potential water supply crisis by 2025: Existing water supplies may not be adequate to meet future demands for society or the environment. This potential crisis is tied to a convergence of factors including explosive population

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growth, increasing demand, static supply, land use change, and drought. Drought has affected Arizona throughout the last decade (Governor's Drought Task Force 2004). Virtually the entire state faced a cumulative water supply deficit in 2004. In 2006 the Phoenix area, which is populated by more 3.5 million residents, experienced the longest period without measurable precipitation on record: 143 consecutive days with no rain. More troubling, recent research indicates that the southwestern United States may be susceptible to droughts lasting 30 or more years and that average precipitation and river flow estimates may be unreliable and based on historical data from an unusually wet period (Piechota et al. 2004).

Water management decision making in Phoenix is complicated by various uncertainties: the effects of global climate change on the urban heat island effect, hydrological cycles, and water supplies; scientific uncertainties associated with global circulation models used to measure and predict climate change (especially the ability of such models to be scaled down to predict regional change); and uncertainties regarding the accuracy of historical data on precipitation and river flows. Additionally, legal and political uncertainties swirl around water rights, especially concerning American Indian tribes and states that share in the allocation of Colorado River water. Finally, there are differences in the ways that scientific and political actors communicate, represent, and employ uncertainty in their discourse and decision-making (Kinzig and Starrett 2003; Shackley and Wynne 1996).

In the face of these challenges, it is clear that scientists and policymakers must work together more effectively to mitigate potential future water crises. For such partnerships to be productive, it is necessary to understand the perspectives of key actors toward the integration of science and policy. Researchers have an opportunity to provide insights into the social context of water issues at a local scale and to develop models of the science–policy interface that enhance the effectiveness of boundary organizations designed to bring scientists and policymakers together. This is the goal of our study.

In this article we examine the perceptions of water managers working at the nexus of science and policy in Phoenix, Arizona. In addition, we discuss the implications of their experiences for the development of an emerging boundary organization: the National Science Foundation (NSF)-funded Decision Center for a Desert City (DCDC). Phoenix water management offers a fruitful opportunity for inquiry because the issues involve scientific and political dimensions with significant uncertainties, and the decision-making community is exploring institutional forms designed to enhance the relationships between stakeholders. Examining water managers' perspectives is informative because these actors interact regularly with scientists and policymakers by conveying policy priorities to scientists and interpreting scientific studies for political decision makers. Three questions guided the research that we present in this article. First, how do Phoenix water managers perceive and negotiate the boundary between science and policy? Second, how do water managers represent, communicate, and manage uncertainty? Third, how can water managers' perceptions about these issues inform the development of a boundary organization?

Before reviewing the water management context in Arizona, we briefly present relevant literature in two areas: uncertainty at the science/policy interface in environmental decision making, and the role that boundary organizations can play at this interface. Next, we present the results of in-depth interviews with 12 water managers from three organizations in the Phoenix area. Lastly, we illustrate how

our interview results informed the development of a prescriptive model of boundary ordering devices and processes to stabilize and enhance the science–policy interface for water management in Phoenix.

Science–Policy Interface in Environmental Decision Making

Science-policy interactions have drawn the attention of scholars in several areas of environmental resources, including forestry (Corley 2004; Joyce 2003; Konijnendijk 2004), climate (Pielke 1995), environmental regulatory policy (Jasanoff 1990; Steel et al. 2004), fisheries (Lee 1993; White and Hall 2006), and water resources (Cash 2001; Lamb 1986). Our focus in this section of the article is to highlight relevant research on criteria or models for successful science–policy interfaces, the concept of boundary organizations, and the role of uncertainty.

Scholars have identified several lessons for successful science–policy interactions. Lamb (1986) noted that policy problems must be open to scientific solutions, technologies must be accepted and trusted, and scientists can both manipulate and be manipulated in the policymaking process. Jones et al. (1999) highlighted the relevance of research to pending decisions, compatibility of research with policy processes, accessibility of research to policymakers, and receptivity of policymakers to research. McCool and Stankey (2004) expressed concern about scientific and technical elites dominating the global sustainability dialogue and offered prescribed roles for interacting scientists (e.g., clarified problem framing, system description and measurement, display/visualization, and interpretation of implications) and policymakers (e.g., goal setting, support and enforcement, evaluation, policy implementation). Lemos and Morehouse (2005) proposed an iterative model of the co-production of science and policy, defined by the level of interaction and social learning between scientists and other stakeholders, the range of uses of scientific knowledge, and practical value of scientific knowledge. The conditions for successful iterative research were defined as interdisciplinarity, interaction with stakeholders, and production of usable science.

Boundary Organizations at the Science–Policy Interface

Studies of the conditions under which the science–policy interface could be enhanced and stabilized led to the examination of the individuals, institutions, and mechanisms that facilitate or constrain effective communication and interaction across the border. In particular, Jasanoff's (1990) analysis of the role of science advisory boards in U.S. regulatory decision-making processes demonstrated that policymaking could be enhanced in situations where boundaries between science and policy were blurred and not sharply drawn (Clark et al. 2005; King et al. 2006).

Subsequent research led to the identification of “boundary organizations” (Guston 2001; Agrawala et al. 2001; Keating 2001; Cash 2001; Cash and Moser 2000; Miller 2001). Guston (2001) provided an introduction to the logic, forms, and functions of boundary organizations and suggested three criteria to characterize them. First, boundary organizations provide the opportunity and incentives for the creation and use of boundary objects and standardized packages (Star and Griesemer 1989; Fujimura 1992). Boundary objects and standardized packages are items such as patents, model research agreements, or computer models that stabilize relations between science and nonscience through mutual consent and use by the

actors in both social worlds. Second, boundary organizations involve the participation of actors from both sides of the boundary, as well as professionals who serve a mediating role. Third, boundary organizations exist at the frontier of the two relatively different social worlds of politics and science, but they have distinct accountability to each. Precisely because they are accountable to both scientific and political systems, Guston (2001) argued that boundary organizations should not be seen to overly politicize science or scientize politics; rather, they exist to provide an opportunity for the stabilization and negotiation of the boundary space that is responsible to both communities.

Cash (2001) examined the boundary organization framework through a case study of agricultural extension and water management in the Great Plains, proposing that the boundary organization was instrumental for creating, maintaining, and mediating relationships between science and policy in the agricultural realm. Cash extended the notion of boundary organizations by introducing three additional hypothesized functions (2001, 442): “(1) they help define the scale of a problem by negotiating the boundaries between levels, (2) they mediate the multidirectional information flows across levels, and (3) they help capitalize on scale-dependent comparative advantages.”

Uncertainty and Boundary Organizations at the Science–Policy Interface

Since the emergence of the precautionary principle in the early 1990s, policymakers have attempted to include the concept of uncertainty more explicitly in the decision-making process. According to Kriebel et al. (2001, 871), the precautionary principle has four key components: “taking preventive action in the face of uncertainty; shifting the burden of proof to the proponents of an activity; exploring a wide range of alternatives to possibly harmful actions; and increasing public participation in decision making.” According to this definition, policymakers should focus on making sure that the availability of critical natural resources, such as water in a semi-arid desert city like Phoenix, does not fall below irreversible levels when they are faced with high degrees of scientific uncertainty. One example of the precautionary principle in Phoenix is the current practice of “water banking” whereby Colorado River water is recharged into groundwater aquifers to protect against future drought.

When there is a high level of uncertainty, and policymakers may be inclined to adopt a precautionary approach, boundary organizations are particularly helpful because they can stabilize and order interactions between science and policy communities (Agrawala et al. 2001). In such instances, uncertainty itself may serve as a boundary-ordering device (Zehr 2000). According to Shackley and Wynne (1996, 280), scientists’ discussions of uncertainty in policy contexts facilitate “interaction, translation, and cooperation between science and policy worlds.” Although Shackley and Wynne (1996) stressed that scientists’ uncertainty discourse performs boundary work by maintaining science’s cultural authority and dominance, the relevant point here is that uncertainty provides a bridge for communication.

Our reading of the literature on science–policy interfaces, boundary organizations, and uncertainty points us to several avenues ripe for investigation in the context of Phoenix water management. First, there is a need for research to expand the list of conditions that explain the co-production of science and policy in environmental resources (Lemos and Morehouse 2005). Second, Cash (2001) specifically called

for more research on the emergence and construction of boundary organizations and examination of the characteristics that make them successful under different circumstances. Third, Phoenix water management is ripe for exploring the role of uncertainty in structuring interactions in science–policy interfaces. With these challenges in mind, we next summarize the water policy framework in Phoenix to provide context for the study.

Study Context: Water Management in Phoenix

On the supply side, four sources of water are available to Phoenix: Colorado River water, other surface water, groundwater, and effluent. Colorado River water is allocated through a complex series of interstate compacts, international treaties, and U.S. Supreme Court decisions (Hobbs 1997). The Central Arizona Project (CAP), completed in 1980, brings about half of the state's 2.5 million acre foot (MAF) Colorado River allocation to the central and southern parts of the state, including the metropolitan regions of Phoenix and Tucson. Surface water from the Salt River and Verde River systems comprises the second source of water, which is managed by the Salt River Project (SRP), the largest surface water supplier in the state. Groundwater is the third supply and is the sole source of water for much of rural Arizona. In a typical year, the City of Phoenix receives approximately 54% of its water from Salt and Verde River surface water, 35% from the Colorado River via the CAP, 7% from effluent, and 4% from groundwater (Quay et al. 2004). Also, in a typical year the City of Phoenix delivers approximately two-thirds of its water to the residential sector (only one-quarter of this residential water use is consumed indoors), and one-third to the nonresidential sector (Quay et al. 2004).

The centerpiece of the water policy framework for Phoenix and Arizona is the 1980 Groundwater Management Act (GMA), which established the goal of achieving safe yield by 2025 by balancing supply and demand with minimal use of groundwater in active management areas (AMAs), which include the metropolitan areas (Jacobs and Holway 2004). One provision of the GMA required determination of an assured supply of water that is physically present, of adequate quality, continuously available for 100 years, and consistent with AMA goals before obtaining approval for new housing subdivisions. In addition to mandating conversion to renewable water supplies, the GMA established provisions for conservation in the agricultural, municipal, and industrial sectors.

Phoenix water managers must consider multiple decision inputs, balance the needs of current and future citizens, protect environmental values, and negotiate complex scientific, technical, and political issues. As mentioned in the introduction, there is increasing concern in Phoenix about future water crises linked to population growth, increasing demand, static supply, land use change, and uncertainty. Clearly, there is a pressing need for research to inform science-based decision making under conditions of inherent uncertainty.

Research Methods

The data presented in this article were collected through a series of in-depth, semistructured interviews with 12 Arizona-based water managers in July and August 2005. After several rounds of pretests, the final interview protocol covered three

general topics: (1) the integration of science and policy in water management decision making; (2) uncertainty; and (3) implications for a boundary organization linking science and policy. The interview questions were open-ended and included probes to elicit complete responses. A digital audio recorder was used to record the interviews, which averaged about 45 min. Respondents represented a diversity of experiences, responsibilities, and perspectives. They were selected using stratified purposive sampling (Patton 1990; Strauss and Corbin 1998). This process began by setting theoretically derived boundaries on potential cases to create a frame. For this, research on boundary organizations and informal contacts was used to determine which managers worked at the nexus of science and policy.

Respondents were selected from three institutional perspectives within the water management community: state water resource managers, state water suppliers, and city water management officials. The four respondents from the state water agency had executive planning, conservation, and decision-making authority for the Phoenix area. Four respondents were from the largest surface water supplier in the region in the state. These respondents were senior-level experts in hydrology, business management, water rights, and environmental science. The last four respondents were from municipalities and had executive experience and responsibilities in planning, administration, and hydrology.

Our qualitative analysis of the interview data followed the procedures outlined by Miles and Huberman (1994). Thus, a team-based strategy was used to develop a codebook to guide the analysis (MacQueen et al. 1998). This process began with a provisional list of start codes—descriptive categories of anticipated themes reflecting the design of the interview protocol. The start codes were broad categories, or “parent nodes,” such as water supply, drought, population growth, science and policy, and uncertainty. Beginning with the start codes, two analysts independently coded all the interviews to develop a more comprehensive system of descriptive codes. During this process, analysts allowed for new categories and subcategories to emerge from the data. For example, emergent descriptive codes or “child nodes” for uncertainty included scientific uncertainty, climatic uncertainty, political uncertainty, and economic uncertainty. The research team (including the two analysts and the authors) subsequently reviewed the new coding systems and discussed discrepancies and differing interpretations. The process continued until each coding category had a definition, an example, and rules for application; an acceptable level of intrarater and interrater reliability was achieved at $\geq 90\%$ (Rust and Cooil 1994).

Next, the analysts returned to the interviews and developed pattern codes and interpretive codes in addition to the descriptive codes (Miles and Huberman 1994). Pattern coding was used to explore relationships among the concepts and to facilitate a constant comparative approach (Strauss and Corbin 1998). The coding system allowed for multiple codes to be applied to any given passage. In addition, we calculated the proportion of interview time that themes co-occurred. Using the proportions of theme prominence and theme relationships, we created data displays to facilitate recognition of patterns. Pattern coding thus allowed the analysts to test their interpretations against the data for negating as well as supporting evidence. Interpretive codes are meant to capture more complex dynamics and typically emerge only after repeated interactions with the data. Interpretive codes allowed for additional contextual distinctions to be made to capture such nuances. Lincoln and Guba (1985) described this part of the coding process as filling in, extending, bridging, and surfacing.

Findings

Two Perspectives on Science and Policy in Water Management Decision Making

Two perspectives emerged about the intersection of science and policy in decision making. The first was a traditional conception of a rational, linear model with distinctive boundaries between science and policymaking. The second perspective was recursive with fluid boundaries. In the linear perspective, managers described a rational process of (1) social and political problem definition, (2) scientific expert advice, and (3) political decision making. Science was described in instrumental terms as a tool to inform, justify, and legitimate decisions. A municipal water manager said scientists should focus on good science—and that it was the city council's job to implement social values. Within this perspective, science is a distinct sphere separate from other systems; scientists are neutral knowledge producers. A respondent with the water supplier said that scientists should not get involved with other considerations or deal with politics or social values. A municipal water services administrator said that science is a “tool,” but the political process is designed to make decisions. This interviewee said that “science provides people the information to understand the implications of their actions . . . they have to decide what is acceptable and what is not acceptable in terms of those actions.” An environmental analyst for the water supplier described a linear perspective, suggesting policymakers first establish priorities and alternatives and “once you figure out the science, then you look at politics and social values” to choose a plan of action.

A different perspective, however, was expressed by several of the interviewees. This perspective was consistent with the concept of co-production of science and policy described by science scholars and policy analysts. The scientific and political spheres were described as interrelated and recursive. Respondents indicated that decision makers actively manage the interaction of science and policy and employ strategies to negotiate and patrol the boundary space. A state water manager said that politicians affect the way the agency conducts scientific inquiry by constraining the types of problems that are studied and the type of information that is used, but also said that political actors do not try to actively “skew the department's scientific analyses.” Managers discussed the interplay of science and politics in the context of “certifying” that adequate water supplies exist as required by the groundwater codes. Managers said that political determination to feed the economic growth machine is a powerful force that sometimes overwhelms other considerations. When hydrological studies, for instance, indicated to state water managers that increased regulation was warranted in growing areas of the state and “science said there wasn't enough water” to support planned development, the political power of the growth industry constrained managers' ability to act. Another manager stated bluntly that “politics has a tendency to deny inconvenient science.”

Interpretive and pattern coding led us to conclude that differences in perspectives among managers were related to professional education, training, and institutional position. Respondents with greater executive decision-making authority and greater interaction with policymakers were more comfortable maneuvering the political landscape and recognized more fluid boundaries between science and policy. Those respondents with traditional scientific education (e.g., hydrology, climatology) and training (and who occupy more technical water “engineering”

positions) were more likely to ascribe to a traditional understanding and were less concerned with “adapting” their science for policy.

The Inescapable Uncertainty of Water Management in Phoenix

A second topic in our interviews with managers was the identification, communication, management, and reduction of uncertainty. The respondents unanimously said that they deal with uncertainty almost every day, including political, climatic, and scientific uncertainty. They also said that decision making under uncertainty was a defining characteristic of water management. Uncertainty was described as “the nature of the beast,” “always present,” and “the whole reason we exist.” One of the greatest sources of decision-making uncertainty arises from a lack of definitive historical data on river flows, precipitation levels, and drought. Managers specifically questioned the completeness of historical drought records and data on average flows for the Colorado, Salt, and Verde rivers. They were also concerned that current water supply and management frameworks may be based on inaccurate information. According to one manager with responsibility for the Phoenix area, “We don’t know for sure about actual Salt and Verde River flows using 100-year averages available. We can deal with the uncertainties year-to-year by doing underground storage and leveling out things for storing for times of shortage, but if our, for example, 100 year average is based on a dry cycle, *that’s* uncertainty.”

Various strategies for measuring, representing, and communicating uncertainty were discussed, and most agreed that it is increasingly important to convey the magnitude of uncertainty to other stakeholders. Strategies ranged from modeling to statistical techniques, such as using variance error bars on charts and figures, to presenting a spectrum of potential future scenarios with “best and worse cases” or “extreme scenarios.” The interviewees recognized that information needs to be simplified for politicians, but it is essential to convey nonetheless, even if only to “hedge.” Despite the widespread uncertainty facing water managers, they discussed several strategies for making decisions with limited information, including “professional judgment.” A senior hydrologist said, “I’ve been doing this for 25 years, and, you know, I’m very good at making up numbers if I don’t get data. We’re good guessers.” A state administrator similarly suggested that by accumulating information there comes “a tipping point” where you feel like you have enough to move forward. In these cases, there is no formula, but rather a “gut feeling” and the question, “Do *I* believe it?”

The potential long-term effects of climate change cause significant uncertainty, and this issue was raised consistently in the interviews. Although all respondents thought climate change worthy of consideration, they also said that a lack of relevant, usable, scientific information compatible with decision processes and timelines limits consideration of climate information in the decision-making process. Other sources of uncertainty are social and political forces. Reflecting the intersection of science and policy discussed earlier, one state administrator said that although there is often uncertainty about the presence of a 100-year supply of water, as required under the assured water supply regulations in the GMA, political forces often encourage the agency to grant permits to allow development. Doubts about future economic growth, the status of legal settlements with Indian tribes, population growth, endangered species designations, and environmental permitting processes were also mentioned, but to a lesser extent.

Enhancing the Science–Policy Interface Through an Emerging Boundary Organization

Following the interviews with Phoenix-area water managers, we presented our interpretations of the themes to a workshop including several of the respondents, as well as involved university research scientists, outside scientific advisors, and political stakeholders. Based on these discussions, we developed a prescriptive model for the science–policy interface within Phoenix water management. One goal of this model is to inform the ongoing implementation of the Decision Center for a Desert City (DCDC), a new institutional arrangement designed to operate as a boundary organization (see Figure 1). The policy sphere includes stakeholder groups engaged in water resources policymaking in the Phoenix area. The science sphere includes scientific research teams from disciplines including geography, climatology, ecology, policy studies, business, economics, and community studies, which were assembled as part of DCDC to generate knowledge relevant for water management decision making under conditions of uncertainty. Opposing pressures and accountabilities for the science and policy actors counteract efforts to stabilize the border. For instance, scientific actors are accountable to university academic units that demand products

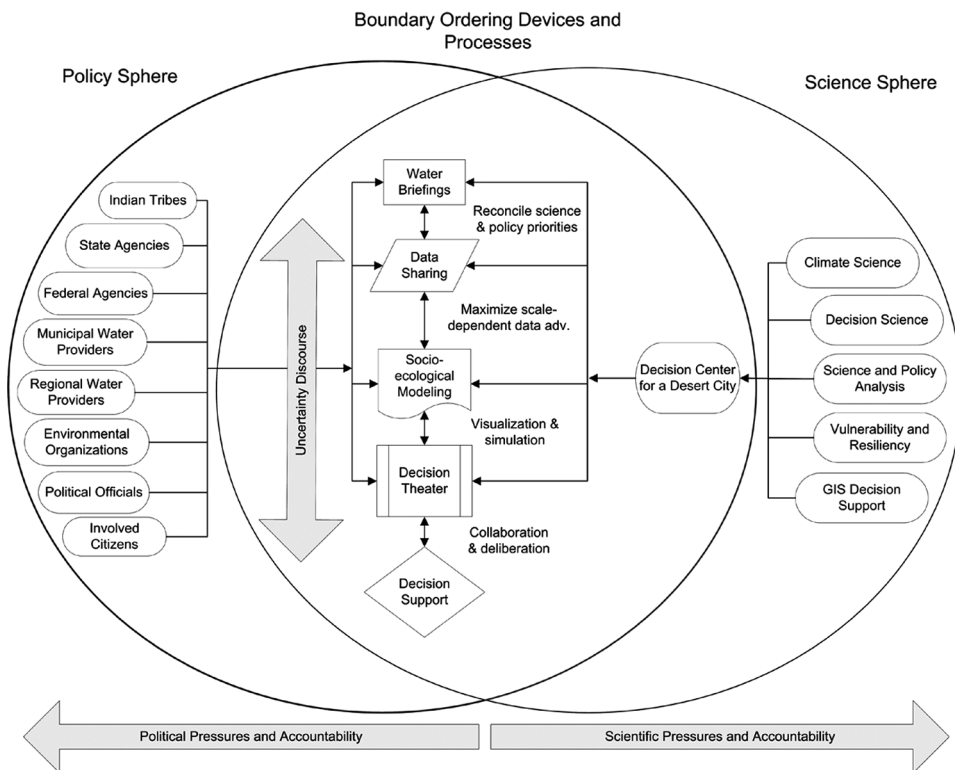


Figure 1. Prescriptive model of science–policy interface for water management in Phoenix. The Decision Center for a Desert City operates as a boundary organization to facilitate boundary-ordering devices and processes to stabilize negotiations between scientific and policy spheres. Uncertainty discourse pervades the boundary space and is embraced as a framework to order discourse.

such as scientific publications and external grant funding. Actors in the policy sphere, on the other hand, are accountable to government agencies, the electorate, constituencies, or shareholders that demand efficiency, action, representation, or return on investment. At the union of these two spheres is a collection of boundary-ordering devices and processes designed to order and stabilize negotiations between the science and policy communities. Pervading the science–policy interface is uncertainty discourse, which is explicitly used as a framework for structuring discussions.

Within the boundary space, it is necessary to reconcile the needs and priorities of the science and policy communities. In the DCDC case, this need is addressed through a series of stakeholders meetings called water briefings. These meetings provide opportunities for stakeholders and scientists to identify knowledge gaps and uncertainties, recognize science and policy constraints, and collaboratively develop research priorities. For instance, managers, scientists, and others decided which variables and processes should be included in a conceptual model of water supply and demand in Phoenix and which policy alternatives should be assessed using the model. The science–policy community decided that economic water markets, although relevant and in use in other Western states, would not be included initially in the model because this policy tool was not considered politically viable in Phoenix at this time.

Another boundary ordering process involves data sharing. Here, the boundary organization serves as a repository to gather, secure, store, integrate, and repackage data from university studies, publicly available data sets, and partnering organizations. This allows for mediating information flows and maximizing scale-dependent comparative advantages (Cash 2001), as data compiled from the various partners allow for analyses not possible from any individual data set. For this process to be successful, water managers and other stakeholders must trust not only the technical capacity but also the security procedures of the boundary organization. Furthermore, the scientific and political actors must negotiate the scale and level of specificity of the data sets. For instance, the water managers we interviewed were cautious about providing water use data for individual households to inform scientific model development (in contrast to aggregated data across census tracts or service areas). Overcoming such concerns requires careful negotiations involving legal counsel and university institutional review boards. Also, this stresses the importance of the development of social capital and personal relationships among actors in the science–policy interface.

The compilation of data sets facilitates the development of mathematical socio-ecological models that serve as boundary objects to be used by both the scientific and water policy communities. All the water managers with whom we spoke were very experienced and comfortable with quantitative water models. The models used by the various agencies, however, are customized and specific to their systems. Managers said that the boundary organization is not likely to have the technical capacity, institutional knowledge, financial resources, or time to construct customized water models for each agency that are as sophisticated as those already in use. Rather, water managers recommended that the boundary organization construct meta-models representing broad-scale water supply and consumption in Phoenix. Although the resulting socio-ecological model must be scientifically credible and comprehensive, water managers stressed that it must be accessible and intuitive to engage policymakers.

Visualization and simulation technology is emerging as an option to link scientific and policy communities, encourage collaboration and deliberation, and improve

boundary dynamics. One example of such technology in use for Phoenix water management is the Decision Theater at Arizona State University. The Decision Theater is an immersive, collaborative decision-making environment that includes a 270-degree three-dimensional theater space. The theater can be used to visualize the stakeholder-developed and data-driven models and construct “what if” scenarios that allow stakeholders to visualize alternative future conditions for system drivers such as population growth, drought, water consumption, land use, land change, heat island effects, and climate change. Using technology such as the Decision Theater allows scientists to represent uncertainty in a manner that is consistent with scientific norms and practices, but that is also accessible to nonscientists with practical expertise in decision making. All of the water managers we interviewed discussed uncertainty as a fundamental aspect of their decision-making processes, and this opens up an avenue for boundary ordering, as scientists also routinely utilize uncertainty in their discourse (Shackley and Wynne 1996). Facilitated collaboration and deliberation among stakeholders allow decision makers to integrate science with other policy inputs to inform water management.

Summary and Conclusion

In this article we have explored water managers’ perceptions of the science–policy interface in Phoenix, AZ. Two contrasting understandings of the intersection of science and politics emerged from the interviews: one model where scientists and policymakers have distinct roles, norms, and functions and operate in largely separate social worlds; and a second model where the boundary between science and policy is less sharply defined and water managers serve as intermediaries who negotiate the boundary space. We also found that managers perceive uncertainty to be a fundamental and inescapable aspect of water management in Phoenix (i.e., something to be represented, managed, and communicated, as opposed to something to be eliminated). Informed by water managers’ experiences, we developed a prescriptive model for an emerging boundary organization that is designed to (1) order and stabilize negotiations between scientific and political actors and (2) inform water management decision making.

Prior research on environmental science–policy interactions highlighted the importance of interdisciplinarity, stakeholder interactions, usable science (Lemos and Morehouse 2005), relevance of research to decisions, compatibility of research to decisions, and receptivity of decision makers to research (Jones et al. 1999). Many of these findings were reinforced by our study. Water managers stressed the need for usable and relevant science that is compatible with decision processes and timescales. Consistent with the findings from the Jones et al. study, the results of our study indicated that climate change research was deemed important, but managers struggled with how to actually incorporate it into decisions. Contrary to McCool and Stankey’s (2004) concern that scientific and technical elites may dominate the science–policy interface, water managers operating in the boundary space in Phoenix were more concerned about political considerations, especially economic growth, being dominant. Social learning and the development of social capital are vital to reconciling science and policy priorities.

Prior work by Guston (2001) and Cash (2001) defined boundary organizations as institutional forms that provide the opportunity and incentives for use of boundary objects that stabilize interactions among social and political actors;

involve actors from both sides of the boundary; have distinct accountability to scientific and political worlds; help define problem scale; mediate information flows; and capitalize on scale-dependent comparative advantages. The DCDC generally meets these criteria, although there is not a clear line of authority to the political sphere. Water managers, who routinely operate in the boundary space, will be instrumental in the potential success or failure of this boundary organization. The findings from this study suggest that those managers ascribing to the recursive model of the science–policy interface will be more adept at (1) assisting researchers in designing and implementing scientific investigations that will generate usable, policy-relevant knowledge, (2) negotiating agreements for data sharing, contributing to model development, (3) visualization and scenario development, and (4) translating findings to policymakers. Our findings reinforce Gustson's (2001) notion that boundary organizations require professionals with specific competencies who serve as intermediaries. Also, our study points to the need for further research to clarify the characteristics, such as prior academic training, professional socialization, and individual personality characteristics, that can enhance an individual's ability to effectively accomplish these tasks.

Our findings also point to the potential of uncertainty discourse as a boundary ordering process. As Kinzig and Starrett (2003), Shackley and Wynne (1996), and Zehr (2000) discussed, the ways in which scientific and political actors understand, represent, discuss, and manage uncertainty in part structure their interactions with each other. In the case of Phoenix water management, uncertainty (including climatic, scientific, and political) is systemic, and thus there is an opportunity to harness it as a unifying force. Our analyses show that the boundary organization (i.e., DCDC in this case) can capitalize on water managers' comfort with uncertainty and enlist them to mediate uncertainty discussions between scientists and policymakers utilizing socio-ecological models and visualizations. Furthermore, uncertainty discourse has implications for policy choices as it can be interpreted to imply either a precautionary approach or a cautious waiting game. Future researchers should examine the discursive construction of uncertainty in naturally-occurring settings and the implications of different uncertainty discourses on decision outcomes (cf. White and Hall 2006).

The ultimate measure of success for integrating science and policy is action that enhances valued environmental and social outcomes. In the case of water management in Phoenix, scientists, policymakers, and other stakeholders face the challenge of averting an impending water crisis while growing an economy, improving equitable access to water, enhancing environmental conditions, and preserving options for future generations. This study offers some support for the notion that boundary organizations have potential to facilitate linkages between communities, but it remains to be seen whether the individuals and institutions have the capacity to meet the challenge.

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