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Credibility, salience, and legitimacy of boundary objects: water managers' assessment of a simulation model in an immersive decision theater

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The connection between scientific knowledge and environmental policy is enhanced through boundary organizations and objects that are perceived to be credible, salient, and legitimate. In this study, water resource decision-makers evaluated the knowledge embedded in WaterSim, an interactive simulation model of water supply and demand presented in an immersive decision theater. Content analysis of individual responses demonstrated that stakeholders were fairly critical of the model's validity, relevance, and bias. Differing perspectives reveal tradeoffs in achieving credible, salient, and legitimate boundary objects, along with the need for iterative processes that engage them in the co-production of knowledge and action.

EFFECTIVE ENVIRONMENTAL POLICY and decision-making requires linking knowledge and action through coordination and communication between individual and institutional actors spanning scientific and political spheres. Several scholars have examined these intersecting spheres in an attempt to understand and enhance the connection between scientific knowledge production and political decision-making with respect to the natural environment (Cash *et al.*, 2003; Guston, 1999; Jasanoff, 1990; Jones *et al.*, 1999; Lemos and Morehouse, 2005; White *et al.*, 2008). A number of key lessons have been identified from this work. First, the way issues are framed can affect how knowledge and action are linked, how the decision space is defined, which actors are empowered or disenfranchised, and ultimately what outcomes result (Hall and White, 2008). Second, the quality of the linkage between knowledge and action is related to stakeholder perceptions of knowledge systems, in terms of credibility, salience, and legitimacy (Cash *et al.*, 2003). Third, research highlights the significance of boundary-spanning processes, organizations, and outcomes that exist at the frontiers of multiple social worlds and facilitate interaction, communication, and stabilization (Cash *et al.*, 2003; Guston, 1999; Miller, 2001; White *et al.*, 2008).

Taking these lessons as a starting point, in this article we present an empirical study of stakeholders' assessment of the credibility, salience, and legitimacy of a particular boundary object in environmental decision-making. By evaluating the

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emergence, developmental path, and the work of organizations involved in boundary management, including negotiating the diverse interests and structuring interactions of actors across science and policy spheres, this research contributes to boundary organizations theory. The context for our study is water resource management in the rapidly urbanizing southwest USA.

The study centers on the experience of water resource decision-makers as they interact with 'WaterSim', an interactive simulation model of water supply and demand that integrates information about climate, land use, population growth, and water policy. The model was developed as part of the Decision Center for a Desert City (DCDC) in an effort to study water management decisions in central Arizona in the context of rapid population growth and urbanization, complex political and economic systems, variable desert climate, and the specter of global climate change. WaterSim is presented in the Decision Theater, a 260-degree, three-dimensional, immersive theater environment.

The study draws upon theory of boundary organizations, boundary objects, and hybridization and employs content analysis of open-ended individual response data gathered from 62 water resource decision-makers with diverse backgrounds and duties. By investigating perceptions of the credibility, salience, and legitimacy of WaterSim, we also aim to provide insight into the intersecting social worlds of water science and water policy. In the next section, we develop the theoretical framework guiding the study, focusing on relevant scholarship on boundary objects, boundary organizations, and knowledge systems for sustainable development. We then describe the context for the study: water resource management in the rapidly growing and urbanizing southwestern USA. Next, we present the individual response data collection strategy, content analysis techniques, and study findings. We close with a discussion of the implications for the study of boundary organization theory and the practice of linking knowledge to action.

Boundary organizations, boundary objects, and hybridization

Boundary organizations are institutional forms, such as policy-relevant research centers, positioned in the overlapping space of scientific research and political decision-making and public action. Boundary organizations theory has been developed in a variety of science-policy contexts, including climate (Agrawala *et al.*, 2001; Cash and Moser, 2000; Miller, 2001), health (Guston, 1999; Keating, 2001), agriculture (Carr and Wilkinson, 2005; Cash, 2001), and water (White *et al*., 2008). The theory owes an intellectual debt to sociological studies of 'boundary work' (Gieryn, 1983, 1995; Jasanoff, 1990), which examine the sometimes strategic and sometimes unconscious tactics that actors use to construct a conceptual boundary between science and non-science, highlighting the practical consequences that arise from the location of that boundary. Boundary organizations:

> refer to those social arrangements, networks and institutions that increasingly mediate between the institutions of 'science' and the institutions of 'politics' — understood as labels for distinct forms of life in modern society. (Miller, 2001: 482)

The initial conceptualization of boundary organizations theory highlighted several basic functions (Guston, 1999, 2001). Boundary organizations provide the opportunity and incentives for the creation and use of boundary objects; they involve the participation of actors from both sides of the boundary as well as professionals who serve a mediating role;

Boundary organizations are not overtly political, but rather they internalize the differences of actors and institutions on both sides of the boundary, negotiate across them to develop decision-making options, and produce boundary objects applicable to either side

and they are distinctly accountable to both political and scientific institutions. Boundary organizations also serve to frame and define the scale of problems, mediate information flows, and capitalize on advantages of scale (Cash, 2001).

Because they have accountability to both scientific and political knowledge systems, Guston (2001), as well as Cash *et al*. (2003), argue 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 responsive to both communities. Boundary organizations are not overtly political, but rather they internalize the differences of actors and institutions on both sides of the boundary, negotiate across them to develop decision-making options, and produce boundary objects applicable to either side. As Guston (2001) stated,

> It is crucial to recognize as an important characteristic the stability it induces by successfully internalizing the boundary negotiations. Its dependence is as important as its independence. (p. 402)

Boundary organizations serve multiple distinct groups not necessarily by blurring boundaries, but rather by bridging boundaries. Boundary organizations encourage adaptation, reinforce convergent interests while permitting divergent interests and unique social norms to persist, and provide a stable structure to reinforce co-adaptation (O'Mahony and Bechky, 2008). That is, boundary organizations establish and maintain the productive tension between science and policy. To capitalize on this productive tension, boundary organizations engage in 'hybrid management' by combining and rearranging scientific and political components (i.e. 'hybridization' and 'deconstruction'), conducting boundary work, and orchestrating activities across social domains (Miller, 2001).

Boundary organizations provide a space for the creation and use of boundary objects, which are hybrid constructs that integrate elements from scientific and political worlds to facilitate the negotiation and exchange of multiple types of knowledge and action. Boundary objects were first described in sociology of science as material or abstract objects that simultaneously inhabit independent but intersecting social worlds; are flexible to the needs of multiple communities; yet durable enough to maintain an identity (Star and Griesemer, 1989). Like boundary organizations, boundary objects are interpretable, bridge social worlds, and facilitate communication across groups. Whereas boundary organizations are more durable, stable institutional forms, boundary objects are more portable, transportable, and material representations, which may be adopted and enrolled by actors on both sides of a boundary. Other hybrid forms have been described, such as standardized packages, which,

> facilitate interactions and cooperative work between social worlds and increase their opportunities for being translated, transferred into, and enrolling members of, other worlds. (Fujimura, 1992: 170)

For example, hybridization of scientific theory and technologies for cancer research provided a stable, enduring definition of cancer and an agreed-upon research agenda (Fujimura, 1988). Boundary objects and hybrids have been examined in a variety of contexts, including organization and management studies (Carlile, 2002; Sapsed and Salter, 2004; Yakura, 2002), geographic information sciences (Harvey and Chrisman, 1998), medical education (Fleischmann, 2006), and climate science (Girod *et al.*, 2009).

Model-based decision-support tools are one type of boundary object that has become increasingly popular for linking environmental science and policy in coupled human-ecological systems. Examples from the water context include:

- The Water Information System for Europe, which provides information about water quality, quantity, and legislation through online 'water live maps' (European Environment Agency, 2009);
- 'RiverWare', a generalized river basin modeling and simulation tool (Zagona *et al.*, 2001); and
- MODFLOW, a three-dimensional finite-difference groundwater model from the US Geological Survey.

Such models offer promise as boundary objects and decision-support tools and have garnered significant investment from science funding agencies. Borowski and Hare (2007), however, identified 'evidence of a mutual misunderstanding' (p. 1049) and gap between water managers and researchers centered on the role and importance of such models, the transferability of models to specific settings, the role of participatory modeling in water management, a lack of confidence in models, the need for improved user interfaces, and model integration. The authors concluded that structural differences between research and policy communities (e.g. divergent interests, accountability, and reward structures) lead to different attitudes toward basic assumptions about the role of models in water management. Boundary organizations offer one opportunity for water science and policy communities to reconcile such structural differences through co-adaptation (O'Mahony and Bechky, 2008).

In prior research, White *et al*. (2008) analyzed DCDC as a boundary organization, following established criteria (cf. Cash, 2001; Guston, 1999, 2001). First, the authors identified a series of hybrid boundary objects and boundary ordering processes. These included: stakeholder meetings designed to reconcile the often divergent priorities of science and policy communities; data-sharing to maximize scale-dependent comparative advantages; and socio-ecological modeling, including WaterSim in the Decision Theater, for visualization, simulation, collaboration, deliberation, and decision support. Second, they showed that DCDC involved participation by actors on both sides of the boundary, as well as professionals who serve in a mediating role. Opposing pressures and accountability for the actors in the two social worlds, however, challenge efforts to stabilize the boundary. The current study extends this line of research by examining the perceived credibility, legitimacy, and salience of the scientific information and technology embedded in WaterSim, as a boundary object.

In summary, boundary organization theory has both analytic and practical utility for environmental decision-making. This scholarship has shown that effective boundary management links the social worlds of scientists and policy-makers. The characteristics of effective boundary organizations include participation, shared accountability, and co-adaptive management. Boundary objects, a class of hybrid, flexible, portable tools, play an important role in helping boundary organizations negotiate knowledge between the science and policy realms. DCDC's WaterSim model is a boundary object designed to bridge boundaries and reinforce shared interests between scientific researchers and water policy stakeholders in central Arizona.

While the literature contains some guidance regarding how boundary organizations and objects can successfully navigate science-policy boundaries, more empirical research is needed to understand the challenges that arise in applying these recommendations. In the next section, we discuss the criteria for boundary management that successfully links knowledge and action.

Credibility, salience, and legitimacy of knowledge constituted in boundary objects

In their synthesis of multiple case studies, Cash *et al.* (2003) highlighted three elements integral to linking knowledge and action for environmental decision-making: credibility, salience and legitimacy. According to the authors:

> *Credibility* involves the scientific adequacy of the technical evidence and arguments. *Salience* deals with the relevance of the assessment to the needs of decision-makers. *Legitimacy* reflects the perceptions that the production of information and technology has been respectful of stakeholders' divergent values and beliefs, unbiased in its conduct, and fair in its treatment of views and interest. (Cash *et al.*, 2003: 8086)

Boundary organizations draw upon scientific institutions to endorse the credibility of the knowledge they produce and look to political institutions to provide legitimacy of the policy implications (Miller, 2001). Three functions that most contribute to successful boundary management to produce knowledge that is credible, salient, and legitimate are: active, iterative, and inclusive communication, translation of scientific knowledge to enhance understanding by decision-makers, and active mediation of conflicts to enhance legitimacy of information while retaining salience and credibility to multiple actors (Cash *et al*., 2003). Furthermore, knowledge systems that are committed to active boundary management are more effective at balancing the salience, credibility, and legitimacy of the knowledges produced.

Like Cash *et al*. (2003), other authors have argued for the importance of establishing the scientific validity, relevance to decision-making needs, and a sense of neutrality and fairness of boundary objects and organizations. For instance, Jones *et al*. (1999) highlighted the relevance of research to pending decisions (salience), compatibility of research with policy processes (legitimacy), accessibility of research to policy-makers (salience), and receptivity of policy-makers to research. Similarly, Lemos and Morehouse (2005) claimed that successful co-production of science and policy relies on 'interdisciplinarity' (i.e. engagement across, among, and within multiple disciplines of thought); interaction with stakeholders (legitimacy); and production of usable science (salience and credibility).

Few scholars have empirically assessed the credibility, salience, and legitimacy of boundary objects in environmental decision-making. A notable exception is a study by Girod *et al.* (2009), which examined the Intergovernmental Panel on Climate Change (IPCC) emission scenarios as hybrid boundary objects and how credibility, salience, and legitimacy changed over three iterations of the IPCC reports. They concluded, based on document analysis and expert interviews, that credibility improved, saliency was reduced over time, and evidence on legitimacy was mixed. They also concluded that tradeoffs existed between salience, credibility and legitimacy in the creation of the scenarios. Such

Tradeoffs between salience, credibility and legitimacy pose serious challenges for those wishing to develop boundary organizations and objects that assist in mediating knowledge among the multiple social worlds involved in environmental decision-making

tradeoffs pose serious challenges for those wishing to develop boundary organizations and objects that assist in communicating, translating, and mediating knowledge among the multiple social worlds involved in environmental decision-making.

With this in mind, the goals of this study are to determine how stakeholders perceive the credibility, legitimacy, and salience of a particular boundary object. Since knowledge perceived to be credible, salient, and legitimate is integral to environmental decision-making, it is important to investigate whether stakeholders perceive knowledge transmitted between social worlds through boundary organizations and objects possesses these qualities, what tradeoffs may exist among these objectives, and what stakeholders' perceptions can tell us about the interaction of science and policy.

Study methods

Study background

The study focuses on the science-policy interactions surrounding DCDC, one of five collaborative groups funded by the National Science Foundation's Decision Making under Uncertainty initiative. DCDC is a policy-relevant research institute that was charged to conduct climate, water, and decision research, and develop decision support tools to bridge the boundary between scientists and decision-makers <http://dcdc.asu.edu>. The environmental policy context is dominated by water resources management decision-making in the Phoenix metropolitan region of central Arizona.

Water is the key resource for growth in Phoenix, which has been among the fastest-growing large metropolitan areas in the USA. The urban region gained more than 800,000 new residents between 2000 and 2006, and is projected to grow from a current population of about four million to nine million or more by 2050. Growth in central Arizona has been defined by increasing control over water supplies, an ever-expanding hydraulic reach, and construction of one of the world's largest and most sophisticated water storage and delivery systems. There is significant concern over the sustainability of the water system in central Arizona, evidenced by policy mandates to limit groundwater overdraft and achieve 'safe yield' (a balance between groundwater withdrawal and recharge) by 2025 (Jacobs and Holway, 2004).

This concern has been exacerbated by significant drought that has gripped the Southwest for more than a decade (Governor's Drought Task Force, 2004). Furthermore, decision-making is complicated by uncertainties such as the urban heat island effect and potential regional impacts of global climate change. Within this uncertain context, several efforts have been launched to link knowledge and action toward a greater sustainability-orientation in water management.

WaterSim: a dynamic water simulation model

This study was organized around water managers' experience with WaterSim, a computer simulation model that projects water consumption and availability in central Arizona under varying scenarios of growth, urbanization, climatic uncertainty, and policy choices from the current time until 2030. The model incorporates four primary components: exogenous uncertainties, policy levers, relationships, and measures for ranking success. Exogenous uncertainties are factors that decision-makers cannot control such as climate and water supply. Policy levers represent potential actions that decision-makers could take, such as groundwater, land, and population-growth management. Relationships describe the mathematical associations between variables in the model. Measures for ranking success reflect how decision-makers assess model outcomes and consist of output displays showing water use across sectors and levels of groundwater depletion across the modeling period.

WaterSim uses climate scenarios and population growth estimates to explore the potential effects of current and projected future water supplies. A 'base case' policy assumes that the system must 'satisfy demand' as presently constituted and that any shortage from surface supply deficits or growth in demand will be balanced by groundwater deficit. WaterSim users can alter the policy to assume 'sustainable groundwater use' under which withdrawal is equal to recharge. Policy choices are then required to balance any deficits in supply. WaterSim uses a GIS framework and Microsoft C# to link a systems dynamics model with a 3-D groundwater water model (MODFLOW) for spatial analyses. WaterSim was developed to be presented in the Decision Theater, a 260-degree three-dimensional interactive environment designed to help decision-makers envision and evaluate policy options (see Figures 1–3).[1]

Data collection, coding, and analysis

The data reported here were collected during 10 two-hour sessions in which participants explored

Figure 1. WaterSim is an interactive simulation model of water supply and demand presented in the Decision Theater, a 260-degree, three-dimensional immersive environment

three simulated scenarios called: 'baseline scenario', 'drought scenario', and 'population growth scenario'. In the baseline scenario, the inputs (Colorado River flow, Salt and Verde River flow, rate of population growth, and rate at which agriculture is converted to residential use) are set at historical and current levels. As a result, the outputs (water sources, water uses, groundwater overuse, and *per capita* daily water consumption) also reflect current and projected future levels.

In the drought scenario, the Colorado River inputs are changed to reflect a historically dry period combined with a 10-year drought at 80% of historical water flow. As a result, storage of Colorado River water drops dramatically, the amount of Colorado River water allocated to Arizona decreases (in accordance with shortage sharing agreements), and by 2030 Maricopa County is forced to pump an additional 8 million acre feet of groundwater beyond what is projected in the baseline scenario. In the population growth scenario, the Maricopa County population grows at 150% of the baseline scenario rate and all agricultural land is converted to residential use by 2030. As a result, policy-makers are unable to subsidize farmers to abstain from production when water is scarce, which has a dramatic effect on the allocations of water use in Maricopa County during droughts. We collected stakeholders' responses to WaterSim and these three scenarios individually prior to group discussions to ensure that responses were not affected by other participants' reactions to the model.

The sampling frame for the study was a list of 308 attendees to the University of Arizona's Water Resources Research Center 2006 Annual Conference. The list contained a broad group of water professionals from the Arizona water management community. All members on the list were contacted via mail, email, or phone. Due to limited capacity in the Decision Theater, we accepted the first 62 people to confirm their attendance and willingness to participate in the study. Participants included representatives of federal, state, local and regional governments, Native American tribes, private and municipal water providers, electricity providers, agricultural users, municipal users, environmental nonprofits, and engineering firms and consultants.

We classified respondents into three decision-making categories (policy-maker, data analyst, or consultant) based on their self-reported professional duties. Ten focus groups were then conducted with relatively homogenous decision-maker groups: two data analyst groups, four policy-maker groups, four consultant groups.

The participants were grouped in this way because we found, in our preliminary research, that people identifying with each of these decision-making categories tend to have similar educational backgrounds and policy perspectives. For example, data analysts tend be very knowledgeable about modeling mechanics, while policy-makers have an intricate understanding of water law, regulatory policies, and the political processes involved in decision-making. European researchers studying

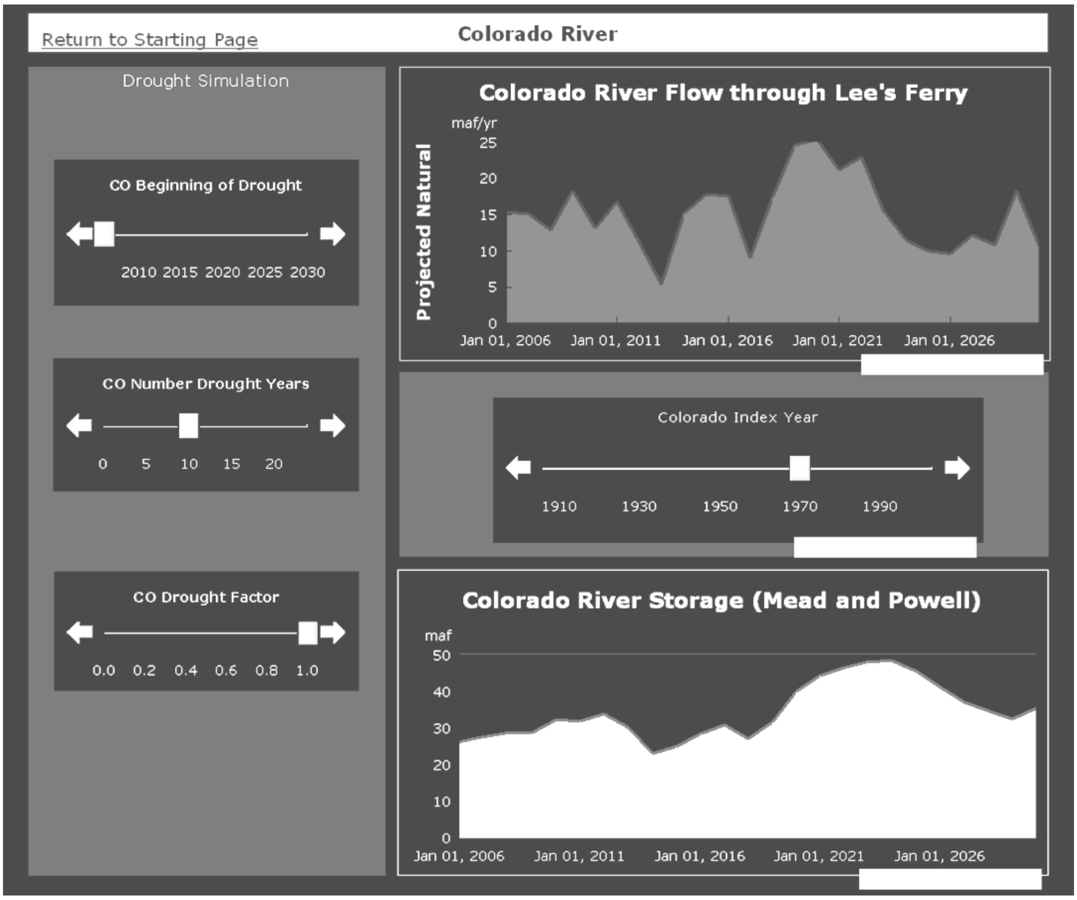

Figure 2. WaterSim screen showing Colorado River flow and storage capacity with 'slider bars' allowing to adjust drought parameters

science-policy interactions for water resource decision-making (Borowski and Hare, 2007) similarly grouped participants based upon professional duties.

The groups were moderated by a professional facilitator, not associated with the scientific information presented or the development of the model. At the start of the session, the moderator gave participants a 20-minute standardized introduction to WaterSim, including the history of the model, the methods used to create the simulations, and how to run different water scenarios. After the introduction, the moderator invited participants to ask questions for clarification on how the model functions, but requested participants hold their comments until after the questionnaire was complete. Once the scripted question-and-answer session was complete, the moderator asked participants to respond to three questions using an open-ended computer-administered questionnaire format:

1. What is your opinion of the technical evidence and arguments presented here?
2. How relevant is the model to your needs as a decision-maker (or the needs of decision-makers in your workplace)? and
3. Do you think that the presentation of information here is fair, unbiased, and respectful of stakeholder values?

The three questions were designed to operationalize credibility, salience, and legitimacy, respectively. The data analyzed for this study come from these individual responses to the open-ended computer-aided questionnaires.

The individual responses were coded by the lead researcher and two research assistants. They developed the final code definitions through an iterative process. Once the code definitions were finalized, two research assistants coded 112 pages of text to establish inter-rater reliability using Cohen's Kappa coefficient (Cohen, 1960). Kappa is a measure of agreement between two coders corrected for chance. Of the 37 codes tested, two had Kappa scores of less than 0.600 (good) and consequently were eliminated from the analysis. In this analysis, we focus on the 20 codes that deal with the credibility, salience, and legitimacy of the boundary object.

Using the data from the 20 codes, we created variables that captured the total number of statements made about each of the individual codes for each of the three participant groups, as well as an overall count. We also calculated the percentage of statements that were coded as either positive, neutral, or negative comments about the credibility, legitimacy, and salience of the WaterSim model overall, as well as percentages for each group (Table 1). Although we recognize that some scholars are hesitant to quantify non-numerical data generated

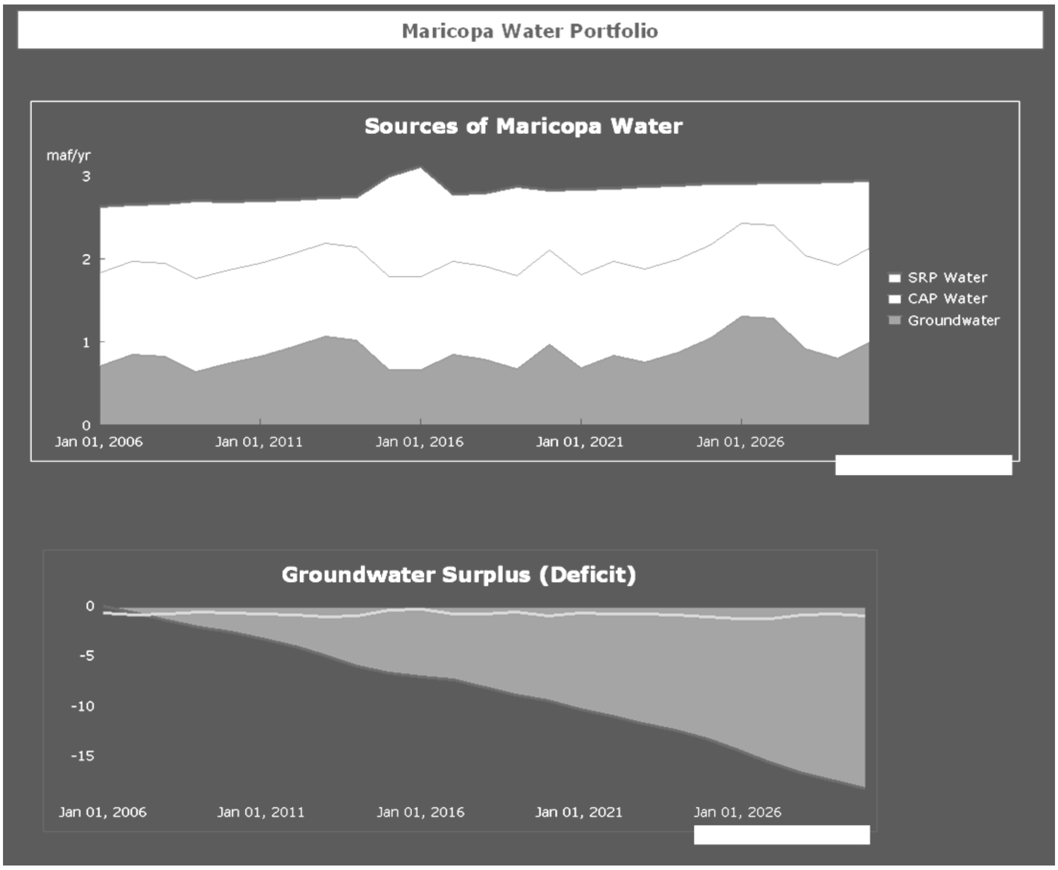

Figure 3. WaterSim screen showing available water supplies and effects on groundwater overdraft under a specific user-generated scenario

through open-ended individual responses, we employed a content analysis approach in this study that is well supported among the community of qualitative researchers (Berelson, 1952; Krippendorff, 2004). This approach has the advantage of allowing us to examine both the quantity (percentage) and the quality (topic and valence) of statements.

Study findings

Credibility

Respondents evaluated the credibility of the boundary object by assessing the scientific validity and technical evidence presented in the model. Their responses were captured by 12 coding categories: neutral, positive, or negative assessments of the data quality, calculations, visual display, and scientific validity (i.e. three 'valence' codes for each of the four 'substantive' codes). Overall there were 292 statements made by respondents about credibility. Of this total, 150 statements (51%) were coded as negative or critical of credibility, 72 statements (25%) as neutral and 70 statements (24%) as positive.

Examining the differences between the groups (see Figure 4) shows that data analysts and consultants were most critical of credibility. For the data analysts, 54% of their comments were negative,

Table 1. Code names, definitions, and inter-rater reliability coefficients

Code	Definition	Kappa	Reliability
Credibility codes			
Data quality	Data that the model uses to run scenarios	0.749	Good
Calculations	Decision rules for the model, mechanics	0.872	Very good
Display	Feedback on the way WaterSim looks	0.657	Good
Scientific validity	Scientific adequacy of the model (accuracy, reliability, precision)	0.657	Good
Salience codes			
Will not adopt	WaterSim cannot be used and does not meet the needs of decision-makers	0.662	Good
Would adopt with modification	Statements such as 'if changed WaterSim would meet the needs of the decision-makers', 'the model could be used if changed'	0.795	Good
Legitimacy codes			
Respect for values	Regards whether the model is/is not respectful of stakeholders' divergent values	1.0	Perfect
Bias	Regards whether the model(er) has a preconceived policy goal, perspective, or opinion	0.745	Good

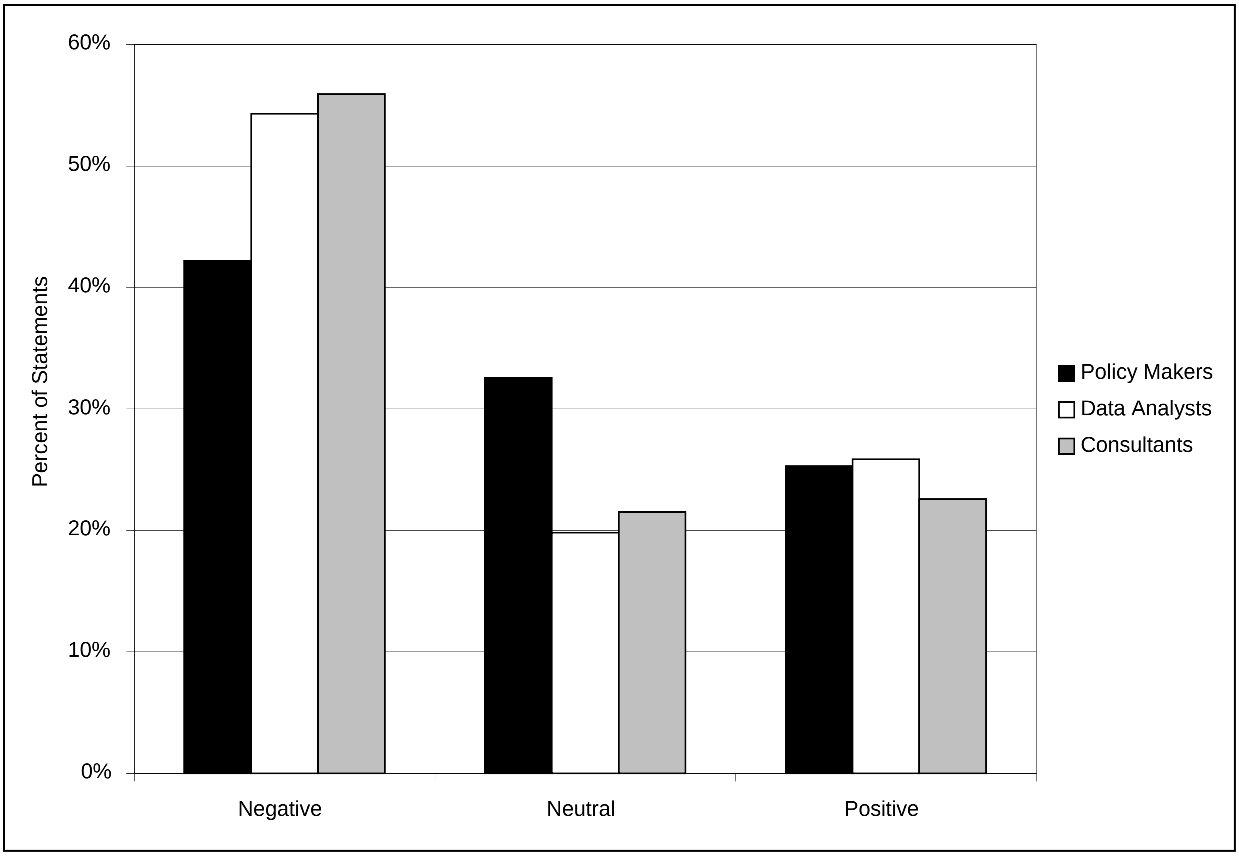

Figure 4. Percentage of credibility statements coded as positive, negative, or neutral by focus group type

while 26% were positive. For the consultants, 56% of their comments were negative and 23% were positive. The policy-maker group evaluated credibility slightly more favorably; 42% of their statements were negative and 33% were positive.

The participants' responses show that favorable assessments of credibility were based on assessments of actual recorded data sources used to develop the model, the diversity of data sources used, and trust that the boundary organization would use the best available data.

Regarding the accuracy and diversity of the data, one policy-maker said:

> It appears that the data was collected from a variety of sources, which would add to the accuracy of the model in determining water levels available in SRP [Salt River Project], CAP [Central Arizona Project], and groundwater.

A data analyst said,

> The model and findings seem to be based on actual recorded data, with projections being based on clear assumptions that can be manipulated to investigate the effects of various changed assumptions.

A policy-maker said,

> By presenting this water modeling information, with real data, and estimated scenarios, based on scientific fact, an accurate model is developed. This will have great value in future decision making in Arizona.

Expressing trust in the scientific community, one respondent said,

> I would feel comfortable in suggesting that the information provided was unbiased and fair based on the best-science available approach.

A data analyst suggested,

> If DCDC has used the best available information or historic record I don't think stakeholders can complain.

As noted earlier, however, half of all responses (51%) across all groups were coded as negative evaluations of credibility.

Several respondents questioned the reliability and validity of the data.

Echoing a scientific debate and questioning data quality, one analyst said,

> But as you know not everyone agrees the data is accurate. Tree ring studies tell us one thing and hydrology tells us something else.

Another data analyst questioned data quality by questioning the accuracy of information drawn from specific sources:

> We and most cities have found DES [Department of Economic Security] and Census data to be wrong based on field experience.

Another reason for questioning credibility was a lack of data. A policy-maker critiqued the data quality by stating,

> Not enough data on Colorado, Salt, Verde River water supplies, and recharge activities.

An analyst criticized the model calculations by saying,

> It doesn't appear that future climate change or the heat island effect were included in projections.

Several respondents questioned the credibility of the model because the model's data for an often-discussed value, residential water use as measured through gallons *per capita* per day, was inconsistent with participants' prior knowledge. For instance, one analyst said,

> *Per capita* use for residential water seems high.

Finally, several respondents did not feel there was accurate information presented in the demonstration to gauge credibility. For instance, this respondent wanted to delve deeper but was frustrated that scientists and model developers were not available during the demonstration to answer questions:

> I cannot assess [credibility] as there is nothing provided as to the science. MAG [Maricopa Association of Governments] is not a scientific agency. Government agencies such as ADWR [Arizona Department of Water Resources] was one source mentioned; was USGS [US Geological Survey]? Again, the scientist needs to be here in order to address this. I have not heard about the [technical] part as presented.

Salience

To assess salience, respondents commented on the relevance of WaterSim to their needs as water resource decision-makers (see Figure 5). Across all respondents, 32 statements were made about the salience of the boundary object. Respondents indicated that they would be inclined to adopt the WaterSim model as a decision-making tool — if modifications were made. Across all groups, 84% of all comments indicated that changes to the model would be required to increase its salience. The participants' responses highlighted a number of modifications that would enhance the salience of WaterSim to their decision-making needs, including issues of geographic scale, institutional specificity, and scenario development.

The consultants in the study were more critical about the utility of the WaterSim model than either the policy-makers or data analysts; one third (33%) of the statements made by consultants were negative, suggesting that they did not find the model relevant to their decision-making, compared with

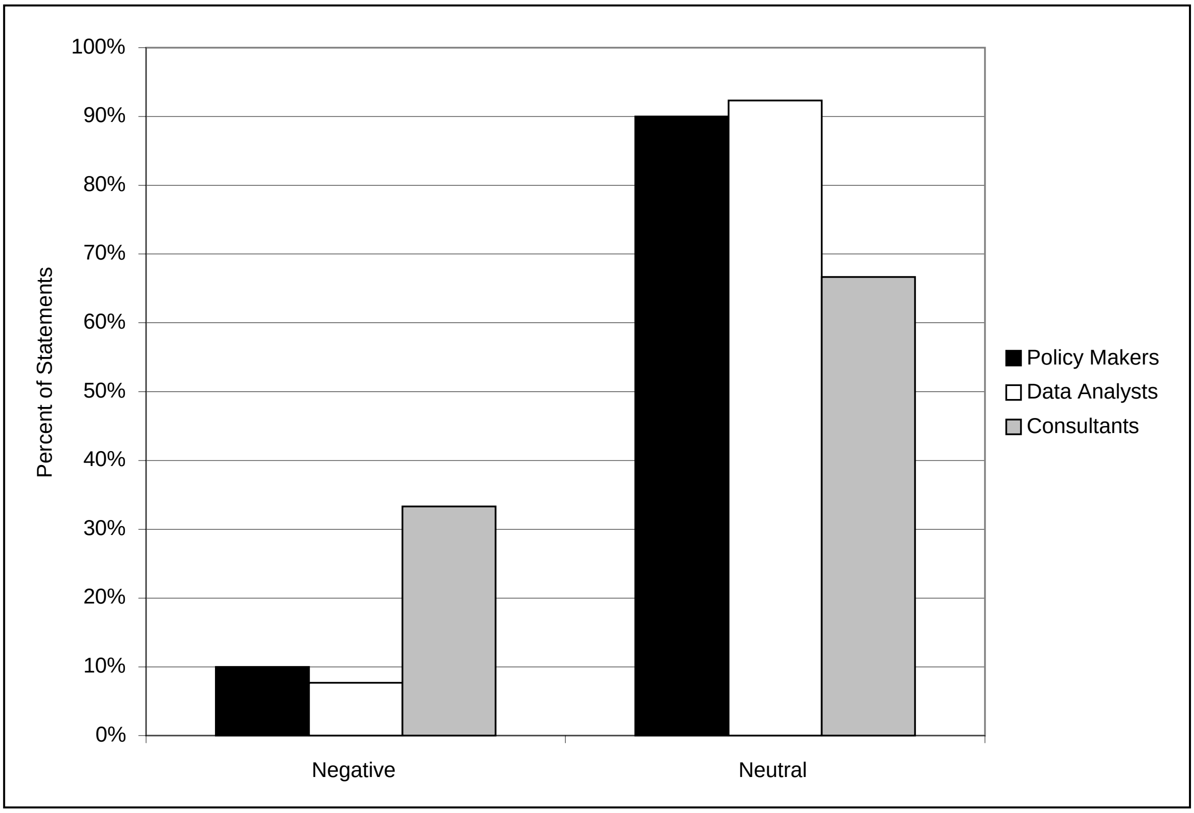

Figure 5. Percentage of salience statements coded as positive, negative, or neutral by focus group type

10% negative comments by the policy-makers and 8% by the data analysts. The policy-makers and data analysts saw more promise in the model; more than 90% of each of these groups' comments indicated that the model would be of use if adjustments were made.

Regarding modifications, several participants recommended 'down-scaling' WaterSim so that model results would be more informative for decision-making for a specific geographic area and/or institution. One consultant said,

> The model may be too broad to assist in a significant way with policy decisions. For instance, you may want to consider breaking Maricopa County down to: SRP [Salt River Project] Service Area and Non-SRP Service Area. Additionally you may want to consider a more spatial analysis using GIS [Geographic Information Systems].

In a second example a consultant found WaterSim to be 'moderately relevant' and 'useful in explaining the big picture associated with potential water shortfalls in Maricopa County' but said:

> the model suffers from its lack of specificity, in the sense that it is difficult to tell how groundwater shortages or surpluses would affect a given water company.

Respondents also said WaterSim would be more relevant to their decision-making needs if additional policy choices or 'levers' were included in the model, especially the ability for model users to affect water price and institute conservation measures. A data analyst said:

> This is a good start. Need to put some type of community economic driver component in, as well as ecosystem demand scenario. Also, maybe a separate [agriculture] component that you can force some kind of water exchange/deficit for [agriculture]. Same for ecosystem water needs.

Legitimacy

The third topic was the legitimacy of the boundary object; that is, the extent to which water decision-makers felt the model was fair, unbiased, and respective of divergent stakeholder values. Overall, the respondents were evenly split. Of the total 108 comments assessing the boundary object's legitimacy, 42% were coded as positive, 42% as negative, and 16% as neutral (see Figure 6). Examining differences between groups, policy-makers were most favorable in their assessment, with 50% of their comments coded as positive compared with 39% positive comments for the data analysts and 40% positive comments for the consultants.

Respondents made 45 positive comments about legitimacy. In particular, respondents praised the science community for opening up the model development process to stakeholder input. A representative statement was made by a policy-maker, who said,

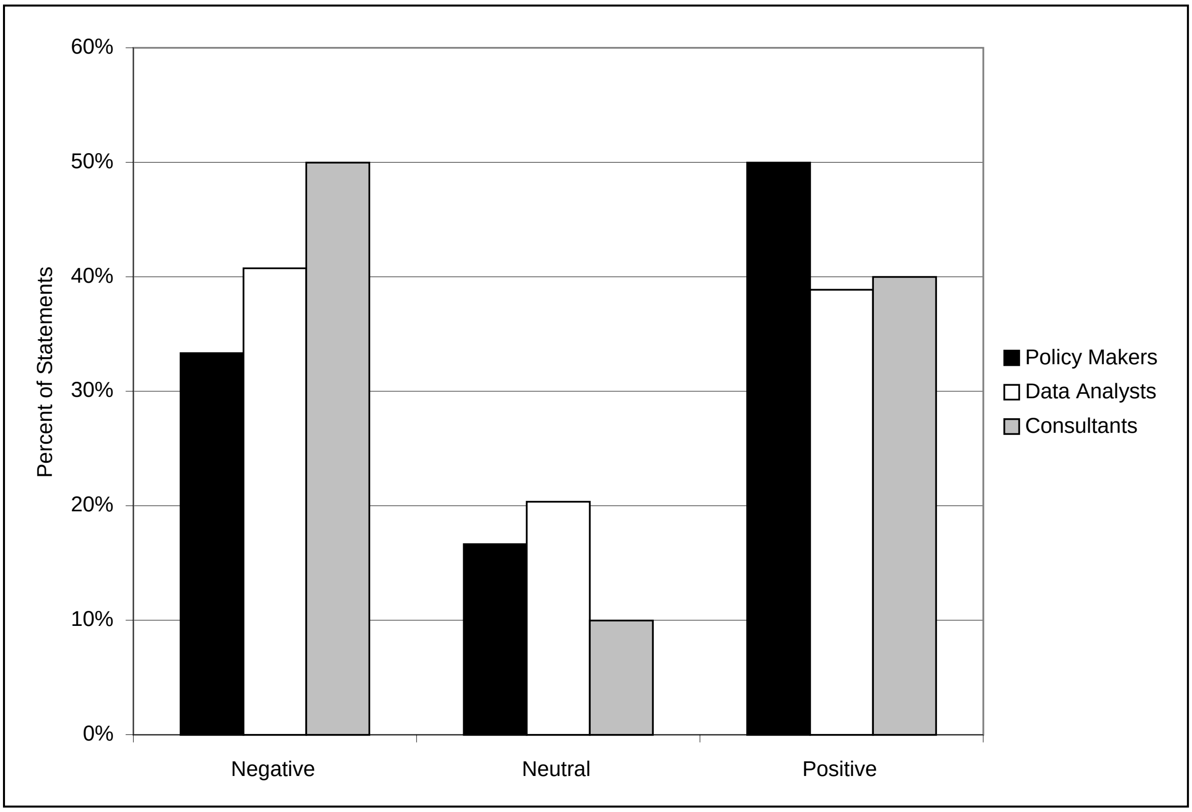

Figure 6. Percentage of legitimacy statements coded as positive, negative, or neutral by focus group type

> By providing the stakeholders the opportunity to view the models and to receive explanation(s) of the assumptions going into the models, the stakeholders have the opportunity to express questions regarding the assumptions.

The stakeholders, however, also made 45 negative comments relevant to their perceptions of legitimacy. One source of concern about bias in the model was that the demand-side of the model did not incorporate requirements for water to support ecosystem services. For instance, one respondent said,

> The information presented is anthropocentric. Every single drop of water available is allocated to some type of human use. I didn't see mention of any water being used to maintain low flows, to support natural vegetation, etc.

Another respondent, a policy-maker, stated,

> I am a little concerned that consideration of water conservation and or limits to growth were not considered in the model (at least not so far). The premise seems to be to allow population growth with no realistic ecological limitations.

A second concern was summarized by a consultant, who was concerned about bias in the model and felt that scientific information and technology was being manipulated to support a pre-determined policy position:

> I am concerned that the information has been devised to drive a decision to a particular conclusion. For instance, in addition to assumptions being incorrect and in some cases not realistic, there is a lack of resource identification, i.e. effluent as a source of water.

Another critique of the information communicated through the boundary object focused on a perceived lack of respect for diverse stakeholder values and positions/claims, specifically Native American rights. One respondent commented,

> Furthermore, failing to account for such senior (aboriginal) upstream claims would be an indication that the model's creators either have not taken the time to research those claims or do not consider them worthy of inclusion, both of which would be highly disrespectful to those senior rights holders and would seriously detract from the model's acceptability among Tribes.

Discussion and conclusion

In this study, water management decision-makers assessed the credibility, salience, and legitimacy of scientific and technical knowledge exchanged by way of a dynamic simulation model presented in an immersive theater environment. The model, WaterSim in the Decision Theater, was analyzed as a hybrid boundary object embedded within a boundary organization designed to link science and policy to improve environmental decision-making under conditions of uncertainty. Three types of decision-makers — data analysts, policy-makers, and consultants — interacted with the model, and then individually evaluated WaterSim. The findings show that, overall, this group of water management decision-makers were critical of the credibility of the knowledge and informational assumptions imbedded in the boundary object; they were skeptical about the salience of the boundary object to their immediate decision-making needs; and they were fairly evenly divided about the boundary object's legitimacy.

While the findings of this study were somewhat humbling to the model developers and boundary organization managers, the generally skeptical perspective expressed by participants was not altogether unexpected

While the findings of this study were somewhat humbling to the model developers and boundary organization managers, the generally skeptical perspective expressed by participants was not altogether unexpected. These respondents evaluated the first version of a complex system dynamics model representing multiple interconnected social and ecological processes with significant uncertainties. Indeed, the boundary organization, committed to co-production of policy-relevant scientific knowledge, engaged these stakeholders early in the development of this decision-making and simulation tool. By opening the 'black box' of model development for the policy community to critique and improve, the boundary organization engaged in the type of hybrid management described by Miller (2001). This study therefore represents a concrete, empirical example of a how boundary organization combines and rearranges scientific and political components to construct, deconstruct, and reconstitute a boundary object.

Our analysis of the qualitative responses revealed some similarities among responses from specific stakeholder groups as well as some differences. Policy-makers were more positive about the model's legitimacy and less negative about the model's credibility than consultants or data analysts. We believe one reason for this may be that WaterSim's 'policy levers', or adjustable model parameters, reflected the variables that are most frequently discussed in the policy community, such as drought, population growth, and water shortage policies. By building the model to reflect conventional decision criteria, we enhanced the model's legitimacy among policy-makers.

This comes at the cost, however, of legitimacy among consultants and data analysts. For instance, many consultants are working to gain recognition for new factors, such as environmental water requirements or Native American water claims among Arizona water policy-makers. As a result, consultants may have been more critical of the model's legitimacy because they felt it exhibited a bias toward the *status quo* and failed to include the perspectives of all stakeholders. Similarly, the WaterSim model used standard government datasets in model calculations, reflecting the conventional analysis methods. However, data analysts are charged with using newer and more precise techniques, such as tree ring records and hydrological studies, to improve our understanding of water availability. As a result, data analysts were more critical and dissatisfied with the model's credibility than other groups.

That modifications would be necessary to increase the salience of the boundary object to water managers is not altogether unsurprising. Prior research indicates that water managers rely heavily on the empirical record and professional judgment for understanding uncertainty and are skeptical about the utility and predictive validity of scenarios and climate models (Borowski and Hare, 2001; Ingram and Lejano, 2007; White *et al*., 2008). The WaterSim model was developed, in part, to facilitate decision-making under uncertainty associated with climate change. Addressing climate change is problematic for local water managers, however, because the impacts are long-term and uncertain, yet the political culture in which these managers operate tends to be short-term. Thus, impacts will occur beyond the tenure of most water managers, who are concerned with a limited geographic area and more immediate uncertainties about economic and population growth, the legal status of Indian water rights, endangered-species designations, environmental permitting, and other components of the water-planning process (White *et al*., 2008).

Our findings indicate the likely presence of trade-offs in credibility, legitimacy, and salience consistent with our expectations and the literature (Cash *et al.*, 2003; Girod *et al.*, 2009). Because WaterSim reflects predominately conventional political concerns about how population growth and the conversion of agricultural lands into urban uses affect water use, consultants and data analysts were dissatisfied with the model's credibility and legitimacy. However, incorporating non-conventional data, methods, or variables into the model may have been seen by some stakeholders as taking an 'activist stance' that deviated too far from DCDC's bridging role as a boundary organization.

This is why the iterative aspect of boundary work is so important; only by responding to the critiques of various actors can stakeholders be continuously engaged and progress made. Indeed, the findings of the research reported were integral to revising WaterSim, which has been redesigned to address stakeholder concerns in terms of credibility, legitimacy, and salience. For instance, to improve credibility, the model developers have been even more engaged with stakeholders and available to answer specific technical questions about the sources, quality, and certainty of the data that drive the model.

To improve salience, the model is now able to run at multiple geographic and institutional scales in the region such as cities or water supplier service areas. Also, new policy levers have been developed for additional conservation policies aimed at reducing residential outdoor water usage such as promoting more dense residential development or reducing the percentage of single-family homes with swimming pools. Policy levers to affect water supply through both price and non-price are currently being integrated into the model.

To increase the model's legitimacy, the boundary organization has been active in soliciting feedback and input from a more diverse range of stakeholders to ensure that their concerns are addressed. Indeed, the study reported here is part of a longitudinal study, and a second wave of stakeholder focus groups has recently been conducted to determine the ability of the boundary organization to improve the credibility, salience, and legitimacy of the boundary object for this group of stakeholders. Preliminary results indicate that DCDC's efforts have been effective in addressing the concerns of key stakeholders regarding credibility, salience, and/or legitimacy. Additionally, similar research is underway with other stakeholders, including members of the interested public. As DCDC moves forward, such communication and outreach to multiple stakeholders is vital because, as Cash *et al*. (2003) noted, boundary management is enhanced by communication that is active, iterative, and inclusive and by effective mediation of conflicts among multiple stakeholder groups.

The findings of this study are consistent with the literature in that measures of validity, relevance, and bias appear to reasonable metrics for assessing knowledge systems at the science-policy interface (e.g. Cash *et al*., 2003; Girod *et al*., 2009; Jones *et al.*, 1999; Lemos and Morehouse, 2005). It is worth mentioning that there are other possible frames for assessing boundary objects. First, research should assess the degree to which hybridization builds and maintains social capacity, denser social networks, and trust among actors. Second, research should continue to address whether boundary organizations and objects effectively reconcile mismatches between the supply of knowledge and the demand for it by actors (Lindblom, 1979; Sarewitz and Pielke, 2007). Third, research should place greater emphasis on not only the methods and institutional forms of boundary organizations and boundary objects, but also the ultimate outcomes. That is, does boundary work effectively serve to illuminate options and consequences of choices and actors' preferences; reframe problems to overcome stagnant and intractable situations; and result in normatively 'better' decisions about environmental science and policy?

In conclusion, it seems that the efforts of the boundary organization to develop a boundary object and associated scientific knowledge that is credible, salient, and legitimate, met with mixed reviews, at least from this set of decision-makers. The actors and institutions of the political sphere, although critical, did hold out hope that the model would be an effective decision-making tool once their needs and concerns were addressed. It is yet to be seen whether the boundary organization can effectively manage the iterative translation and communication between the various actors to create an effective boundary object.

Note

1. A web-based version of WaterSim is available at http://watersim.asu.edu/, and may be used to investigate the impact of climate change, population growth, and policy interventions on water availability in Phoenix.

References

Agrawala, S, K Broad, and D H Guston 2001. Integrating climate forecasts and societal decision making: challenges to an emergent boundary organization. *Science Technology and Human Values*, **26**(4), 454–477.

Berelson, B 1952. *Content Analysis in Communication Research*. Glencoe, IL: Free Press.

Borowski, I and M Hare 2007. Exploring the gap between water managers and researchers: difficulties of model-based tools to support practical water management. *Water Resources Management*, **21**(7), 1049–1074.

Carlile, P R 2002. A pragmatic view of knowledge and boundaries: boundary objects in new product development. *Organization Science*, **13**(4), 442–455.

Carr, A and R Wilkinson 2005. Beyond participation: boundary organizations as a new space for farmers and scientists to interact. *Society and Natural Resources*, **18**(3), 255–265.

Cash, D W 2001. 'In order to aid in diffusing useful and practical information': agricultural extension and boundary organizations. *Science Technology and Human Values*, **26**(4), 431–453.

Cash, D W and S C Moser 2000. Linking global and local scales: designing dynamic assessment and management processes. *Global Environmental Change-Human and Policy Dimensions*, **10**(2), 109–120.

Cash, D W, W C Clark, F Alcock, N M Dickson, N Eckley, D H Guston *et al.* 2003. Knowledge systems for sustainable development. *Proceedings of the National Academy of Sciences of the United States of America*, **100**(14), 8086–8091.

Cohen, J 1960. A coefficient of agreement for nominal scales. *Educational and Psychological Measurement*, **20**, 37–46.

European Environment Agency 2009. The Water Information System for Europe. <http://water.europa.eu/en/welcome>, last accessed 31 July 2009.

Fleischmann, K 2006. Boundary objects with agency: a method for studying the design-use interface. *Information Society*, **22**(2), 77–87.

Fujimura, J 1992. Crafting science: standardized packages, boundary objects, and 'translation'. In *Science as Culture and Practice*, ed. A Pickering, pp. 168–211. Chicago: University of Chicago Press.

Fujimura, J H 1988. The molecular biological bandwagon in cancer-research – where social worlds meet. *Social Problems*, **35**(3), 261–283.

Gieryn, T F 1983. Boundary-work and the demarcation of science from non-science – strains and interests in professional ideologies of scientists. *American Sociological Review*, **48**(6), 781–795.

Gieryn, T F 1995. Boundaries of science. In *Handbook of Science and Technology Studies*, eds. S Jasanoff, G E Markle, J C Petersen and T Pinch, pp. 383–443). London: Sage.

Girod, B, A Wiek, H Mieg and M Hulme 2009. The evolution of the IPCC's emissions scenarios. *Environmental Science and Policy*, **12**(2), 103–118.

Governor's Drought Task Force 2004. Arizona Drought Preparedness Plan. <http://www.water.az.gov/gdtf/>, last accessed 10 August 2005.

Guston, D H 1999. Stabilizing the boundary between US politics and science: the role of the Office of Technology Transfer as a boundary organization. *Social Studies of Science*, **29**(1), 87–111.

Guston, D H 2001. Boundary organizations in environmental policy and science: an introduction. *Science Technology and Human Values*, **26**(4), 399–408.

Hall, T E and D D White 2008. Representing recovery: science and local control in the framing of US Pacific Northwest salmon policy. *Human Ecology Review*, **15**(1), 32–45.

Harvey, F and N Chrisman 1998. Boundary objects and the social construction of GIS technology. *Environment and Planning A*, **30**(9), 1683–1694.

Ingram, H and R Lejano 2007. Why institutions resist incorporating climate change scenarios into agency practice. Presented at the International Symposium on New Directions in Urban Water Management, UNESCO, Paris, France, 12–14 September 2007. <http://www2.gtz.de/Dokumente/oe44/ecosan/en-institutions-resist-climate-change-scenarios-practice-2007.pdf>, last accessed 15 June 2009.

Jacobs, K L and J M Holway 2004. Managing for sustainability in an arid climate: lessons learned from 20 years of groundwater management in Arizona, USA. *Hydrogeology Journal*, **12**, 52–65.

Jasanoff, S 1990. *The Fifth Branch: Science Advisers as Policymakers*. Cambridge, MA: Harvard University Press.

Jones, S A, B Fischhoff and D Lach 1999. Evaluating the science-policy interface for climate change research. *Climatic Change*, **43**(3), 581–599.

Keating, T J 2001. Lessons from the recent history of the health effects institute. *Science Technology and Human Values*, **26**(4), 409–430.

Krippendorff, K 2004. *Content Analysis: an Introduction to its Methodology*,2nd edn. Thousand Oaks, CA: Sage.

Lemos, M C and B J Morehouse 2005. The co-production of science and policy in integrated climate assessments. *Global Environmental Change-Human and Policy Dimensions*, **15**(1), 57–68.

Lindblom, C E 1979. *Usable Knowledge: Social Science and Social Problem Solving*. New Haven: Yale University Press.

Miller, C 2001. Hybrid management: boundary organizations, science policy, and environmental governance in the climate regime. *Science Technology and Human Values*, **26**(4), 478–500.

O'Mahony, S and B A Bechky 2008. Boundary organizations: enabling collaboration among unexpected allies. *Administrative Science Quarterly*, **53**(3), 422–459.

Sapsed, J and A Salter 2004. Postcards from the edge: local communities, global programs and boundary objects. *Organization Studies*, **25**(9), 1515–1534.

Sarewitz, D and R A Pielke 2007. The neglected heart of science policy: reconciling supply of and demand for science. *Environmental Science and Policy*, **10**(1), 5–16.

Star, S L and J R Griesemer 1989. Institutional ecology, translations and boundary objects: amateurs and professionals in Berkeleys Museum of Vertebrate Zoology, 1907-39. *Social Studies of Science*, **19**(3), 387-420.

White, D D, E A Corley and M S White 2008. Water managers' perceptions of the science-policy interface in Phoenix, Arizona: implications for an emerging boundary organization. *Society and Natural Resources*, **21**(3), 230–243.

Yakura, E K 2002. Charting time: timelines as temporal boundary objects. *Academy of Management Journal*, **45**(5), 956–970.

Zagona, E A, T J Fulp, R Shane, Y Magee and H M Goranflo 2001. Riverware: a generalized tool for complex reservoir system modeling. *Journal of the American Water Resources Association*, **37**(4), 913–929.