Water Resour Manage (2017) 31:4731–4744
DOI 10.1007/s11269-017-1775-6

Participatory Modeling Workshops in a Water-Stressed Basin Result in Gains in Modeling Capacity but Reveal Disparity in Water Resources Management Priorities

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Received: 11 April 2016 / Accepted: 19 July 2017 /

Abstract Participatory modeling workshops were held in Sonora, México, with the goal of developing water resources management strategies in a water-stressed basin. A model of the water resources system, consisting of watershed hydrology, water resources infrastructure, and groundwater models, was developed deliberatively in the workshops, along with scenarios of future climate and development. Participants used the final version of the water resources systems model to select management strategies. The performance of the strategies was based on the reliability of meeting current and future demands at a daily time scale over a year's period. Pre- and post-workshop surveys were developed and administered. The survey questions focused on evaluation of participants' modeling capacity and the utility and accuracy of the models. The selected water resources strategies and the associated, expected reliability varied widely among participants. Most participants could be clustered into three groups with roughly equal numbers of participants that varied in terms of reliance on expanding infrastructure vs. demand modification; expectations of reliability; and perceptions of social, environmental, and economic impacts. The wide range of strategies chosen and associated reliabilities indicate that there is a substantial degree of uncertainty in how future water resources decisions could be made in the region. The pre- and post-survey results indicate

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that participants believed their modeling abilities increased and beliefs in the utility of models increased as a result of the workshops.

Keywords Participatory modeling · Water scarcity

1 Introduction

Water scarcity and its socioecological consequences are serious risks to human well-being, in terms of the likelihood and impact of the risk (Kummu et al. 2010; Howell 2013; Vörösmarty et al. 2013; Veldkamp et al. 2015). Governance strategies for managing water resources must be able to adapt to changing hydro-climatic and socioeconomic conditions and political contexts (Wiek et al. 2006, Pahl-Wostl 2007a, Ostrom 2009). Transitions to sustainable water governance are more likely to occur through participatory methods where alternative responses to scarcity and their impacts are explored (Pahl-Wostl et al. 2007b, Veldkamp et al. 2015, Malve et al. 2016). Participatory modeling (PM) has emerged as a tool to assist decision-making processes through embedded participation of the stakeholders, decision makers and other experts (e.g., Jones et al. 2008; Gaddis et al. 2010; Voinov and Bousquet 2010; Gray et al. 2012; Addison et al. 2013; Laniak et al. 2013; Babbar-Sebens et al. 2015).

Successful PM efforts generate new knowledge and support iterative, collective decision-making (Bousquet and Tréibul 2005; Gurung et al. 2006). When models are created through collaborative efforts, they can serve as platforms where disparate perspectives can be discussed and common understanding can be achieved, resulting in the generation of credible alternatives for resolving natural resource management issues (Cash et al. 2003; van den Belt 2004). Most PM efforts in the water resources arena are aimed towards building consensus towards water management decisions (von Korff et al. 2012). However, in cases where water resources conflicts are especially entrenched, future biophysical and socioeconomic conditions are particularly uncertain, and where collaborative decision making efforts are in nascent stages, PM offers the opportunity to explore the diversity of existing viewpoints as a means for co-producing knowledge (Pahl-Wostl 2009; Zorrilla et al. 2009; Langsdale et al. 2013; Scholz et al. 2014; Butler and Adamowski 2015).

While there are many positive aspects of collaborative modeling, participants may not engage in the modeling effort if they lack the necessary modeling skills and knowledge (Renger et al. 2008). This means that PM efforts need to include appropriate activities to ensure that models do not become a “black box” for participants (Butler and Adamowski 2015). However, PM efforts have rarely been evaluated with respect to gains in participants’ capacity to use models. Furthermore, no studies have examined the relationship between the attributes of collaboratively developed management strategies and participants’ evaluation of model accuracy and utility and their own modeling skills.

The goal of this work is to contribute to the literature on participatory modeling in the field of water resources management by addressing the following questions:

(a) how do participatory modeling workshops contribute to participants’ capacity and confidence in using models and does the degree of capacity and confidence depend on incoming perceptions?

(b) How do participants' selection of management strategies, in the context of uncertain future conditions, vary and how do these selections depend on participants' views of their confidence in using models?

(c) what is the diversity of "best" water management strategies chosen by the participants and do these choices depend on beliefs about the impacts of the strategies?

2 Study Area

The PM workshops took place in Hermosillo, Sonora, Mexico, located in the Rio Sonora basin (RSB). The RSB is an arid to semiarid region with an average annual rainfall of 420 mm. Potential evapotranspiration exceeds precipitation on an annual basis, resulting in low stream discharges during most of the year which amounts to ~5% of the rainfall falling in the RSB on annual basis (Vivoni et al. 2010). The region experiences high intra-seasonal and inter-annual climate variability due to the effects of the North American Monsoon and other teleconnection patterns (Robles-Morua et al. 2014). This hydro-climatic variability, coupled with urban and agricultural demands and limited water resources infrastructure, challenges management of water supplies in the RSB which consist of a surface water reservoir, known locally as "El Molinito", and a series of groundwater aquifers. Recent developments, such as the construction of a 180-km aqueduct from the Rio Yaqui basin to Hermosillo, have exacerbated political conflicts over water.

3 Methods

3.1 Workshop Format and Survey Instrument

We conducted three PM workshops with four full- or half-day sessions that took place over a four-month period. We invited 150 individuals from federal, state, and local natural resources agencies; non-governmental organizations (NGOs); the private sector; and local universities. The first workshop was designed to: (a) develop a common understanding of the RSB climate, hydrology, and water use; (b) agree on a preliminary structure of the models to be used in subsequent workshops; and (c) allow the participants to experiment with modeling software using draft versions of the models. A pre-survey was administered before the start of the first day of workshops. Fifty-four invitees participated and 53 took the pre-survey. In the second workshop, new results of the hydrologic model demonstrating the impacts of climate change on water supply availability in the RSB were presented and discussed. The features of the revised water resources systems model (WRSM) were presented and the participants experimented with the model in a series of hands-on activities, providing feedback on preferred model improvements to the workshop organizers. A set of potential water supply and demand augmentation options was identified by the participants. Finally, the participants discussed the future climate and development scenarios that would be available to drive the WRSM. Twenty-eight individuals attended the second workshop.

The third workshop was dedicated to the development of management strategies using the final version of the WRSM. Thirty participants attended the third workshop and had access to a laptop computer containing the WRSM. Participants discussed how to use the model to make their choices of water supply and demand options, what "best-case strategy" meant to them and what the potential environmental, social, and economic impact could be for a given strategy. Participants were asked to complete a questionnaire to: (a) rate the expected environmental, social, and economic impacts of their chosen management strategy, based on a three-point Likert scale: significant negative impacts; little or no impacts; and significant positive impacts; (b) rate the personal importance of the expected environmental, social, and economic impacts based on a three-point Likert scale: very important; neutral or little importance, and not at all important; and (c) comment on the expected environmental, social, and economic impacts. The selected water supply and demand strategies were downloaded from the individual computers, linked to the rated impacts through a user number, and stored for future analysis. The post-survey was administered at the end of the workshop.

3.2 Water Resources Systems Model (WRSM)

The WRSM has three components: (1) water balance models for surface and groundwater storages, based on natural- and human-derived inflows and outflows; (2) optional climate and development scenarios; and (3) options for water supply augmentation and demand management. A graphical user interface (GUI) was constructed to allow the user to select different options and run the model to assess water supply availability. The water balance models are summarized in Fig. 1. For the groundwater supplies, the RSB is divided into 12 groundwater aquifers, according to delineations of CONAGUA (2016). Single-cell, annual water balance models were used to simulate aquifers:

$$\frac{\Delta S}{\Delta t} = LI + R - LO - (W - RF) \tag{1}$$

where $\Delta S/\Delta t$ is the change in groundwater storage, LI and LO are lateral inflows and outflows, R is recharge, W is withdrawals, and RF are return flows. Aquifers are connected through the lateral flows, based on proximity. Annual lateral inflows and outflows and recharge rates were obtained from CEA (2005). Fully-discretized groundwater models for individual aquifers cannot be justified, due to insufficient, spatially-distributed hydrogeologic information.

The daily water balance for the "El Molinito" reservoir is:

$$\frac{\Delta S}{\Delta t} = IF - OF - ER \tag{2}$$

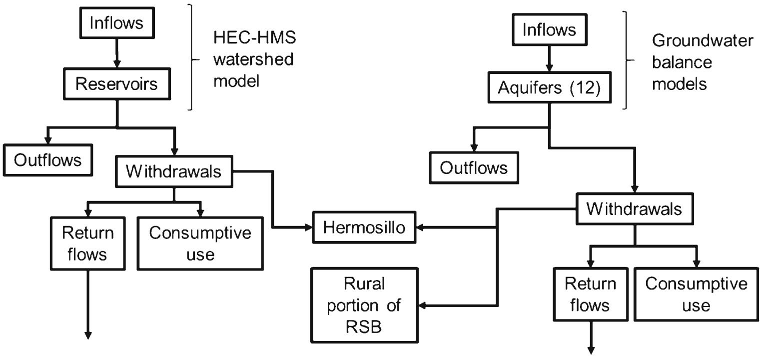

Fig. 1 Water resources systems model framework

where *IF* is inflow, *OF* is outflow, and *ER* is evaporative loss from the reservoir surface. Outflows are withdrawals for water demands when reservoir storage is available. Evaporative losses are calculated based on a daily evaporation rate and multiplied by reservoir surface area. A surface water hydrology model was built with the Hydrologic Modeling System (HEC-HMS) to provide inflows to the reservoir, due to its extensive application worldwide (e.g., Meenu et al. 2012; Acharya et al. 2013; Ebrahim et al. 2013). Model parameters were determined from soil texture and land cover data for the basin (Whitten et al. 2014; Robles-Morua et al. 2015).

Meteorological variables in the RSB are derived from a network of 30 climate stations from 1980 to 2010 and from regional simulations from the Weather and Research Forecasting (WRF) model over historical (1990–2000), near future (2031–2040) and far future (2071–2079) periods (Robles-Morua et al. 2015). The WRF model provides hourly precipitation, solar radiation and air temperature fields at a 10 km resolution, downscaled from the coarser predictions of the HadCM3 and MPI-ECHAM5 General Circulation Models (GCM) with the A2 emissions scenarios (Whitten et al. 2014 and Robles-Morua et al. 2015).

Water demands are divided into the Hermosillo urban area and the remainder of the basin, which consists of rural communities and irrigated agricultural areas. Withdrawals for residential, commercial, industrial, irrigated agricultural and livestock uses are assigned as outflows from the “El Molinito” reservoir or one of the 12 groundwater aquifers. Withdrawals are based on historical unit demands for each water use category and withdrawal source (CEA 2005, Agua de Hermosillo, 2013) and historical or projected changes in population and land use.

3.3 User Inputs: Scenarios and Options for Water Supply and Demand Management

User inputs for the WRSM were developed based on participant preferences that evolved during the workshop discussions and fall into four broad categories: (a) climate scenarios, (b) development scenarios, (c) water supply augmentation or reduction and demand management strategies, and (d) uncertainty in the water balance models. For the climate scenarios, users could select from the wettest or driest years or the year closest to the average annual precipitation for each simulation periods (historical, near future or far future), for a total of 9 climate scenarios.

Users could choose from three development scenarios based on current trends or anticipated shifts in urban and rural populations and irrigated farmland: (a) the “Hyper” scenario assumed continual urban and industrial expansion; (b) the “Plateau” scenario assumed rapid urban and industrial expansion until 2030, followed by constant urban population and irrigated agricultural areas; and (c) the “Crash” scenario assumed rapid urban and industrial growth until 2030, followed by declines in urban population and constant irrigated agricultural areas. Options for water supply and demand management are listed in Fig. 2, along with the ranges available for each option. Finally, users could assess the impacts of uncertainty in groundwater recharge rates by increasing or decreasing the estimates of all aquifer recharge rates by up to 50%.

3.4 Analysis of Workshop Impacts on Participants

Participant pre- and post-surveys were developed and administered to assess the impacts of the workshops on beliefs regarding causes, solutions and impacts of regional water-related problems; climate change; and hydrologic and water resource systems modeling. The

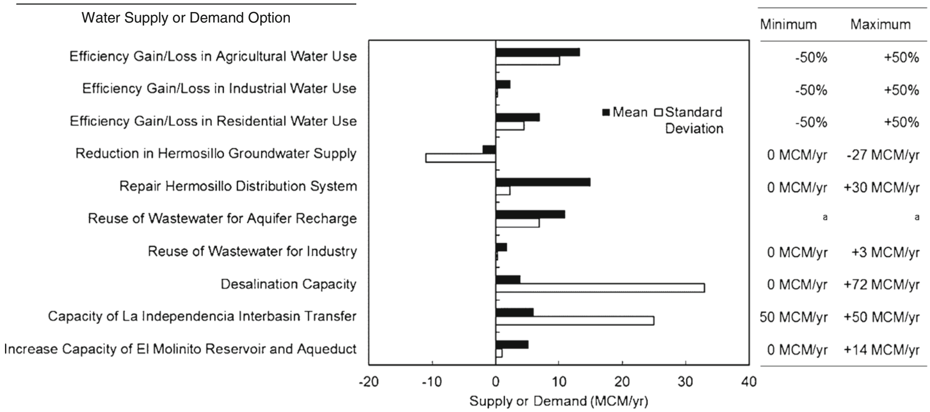

Fig. 2 Water demand and supply options and constraints and results for mean and standard deviation of supply or demand augmentation or diminishment selected by participants

questions regarding model use, comfort with models, and trust in models were developed based on Brenna's (2012) assessment of the role of water resources modeling in the RSB. Additional questions addressed the quality of the workshop process and outputs. The surveys also included demographic information such as the participants' gender, age, educational level, and organizational affiliation. We focus here on the survey questions designed to measure beliefs about participants' capacity to use and understand models, and model usefulness and accuracy.

The pre-survey included 81 questions, 43 focused on modeling, including participants' prior experience with it. The post-survey included 98 questions, repeating 36 of the modeling questions from the pre-survey, with an additional 24 questions about the workshop quality (see Supplemental Information for survey). A survey numbering system was used to link individuals' pre- and post-survey responses. The survey questions were designed to be grouped into sets to create indices measuring the following variables: participant's prior experience with models (pre-survey only), beliefs about personal capacity to use and understand models, model usefulness, and model accuracy. Survey items were assessed for their viability as scales using Cronbach's alpha values of $\alpha > 0.6$ as a standard for index viability. The *t*-test statistic was used to determine the significance of mean respondent index changes before and after the workshop. The survey data was analyzed using the statistical software SPSS®.

The indices were further analyzed to assess whether the level of prior experience affected the level of post-workshop beliefs about personal capacity, usefulness, and accuracy. The post-workshop index values "Beliefs about personal capacity to use and understand water models," "Beliefs about usefulness of water models," and "Beliefs about accuracy of water models" were compared to the scale values for "Participant's prior experience with models," by participant. Individual linear regressions were produced with each of the three post-workshop scales as dependent variables and prior experience and three demographic variables as independent variables. The independent demographic variables were: gender; age; educational level, represented as a categorical variable; and organizational affiliation, represented as a categorical variable. Two-tailed *p*-values for the null hypothesis for the slope (slope = 0) were estimated for the coefficients associated with the independent variables for each of the three regressions.

3.5 Classification of Participants into Groups

The tendency of the participants to arrive at a consensus or partition into separate groups was analyzed by applying cluster analysis to the four classes of measurement attributes (total attributes = 14): (a) the magnitude of the water supply augmentation or reduction (seven attributes); (b) the magnitude of the expected increase or decrease in water use efficiencies (three attributes); (c) the Likert scales for the expected environmental, social, and economic impacts associated with the chosen management strategy (three attributes); and (d) the water supply reliability of the chosen strategy, averaged over all of the climate and development scenarios (one attribute). Principal component analysis (PCA) with varimax rotation was applied to determine whether the dimensionality of the problem can be reduced to a smaller number of principal components; however, this analysis did not result in an obvious set of new dimensions.

A two-step clustering algorithm (SPSS®) was used because previous experience has shown that this algorithm is superior to single stage algorithms using hierarchical or k-means clustering (Mayer et al. 2014). Based on the results from the first step, a modified hierarchical agglomerative clustering procedure combines the objects sequentially to form homogenous clusters and clusters are then sequentially merged according to their similarity. The performance of the clustering algorithm was assessed with a post-hoc analysis of significance in differences between attribute means across groups. The Dunnett's T3 post-hoc test was chosen for comparing means of populations because it is appropriate for datasets with unequal variances and sample sizes (Dunnett 1980). This test results in calculating the fraction of attribute-pairwise classifications with an F statistic at a 0.05 significance ($F_{p < 0.05}$). In addition, the silhouette coefficient (SC, Rousseeuw 1987) was calculated to measure how closely an attribute value is matched to data within its group and how loosely it is matched to data in other groups. The relationship between groups and beliefs about modeling capacity, model capacity and model accuracy was assessed by calculating mean scales for each group. The significance of differences between mean scales between groups was determined with a *t*-test between pairs of groups.

4 Results

4.1 Participant Demographics

Of the 52 participants that completed a pre-survey and participated in at least one workshop, 33% were female, 20% had a Bachelor's degree only, and 60% had a graduate degree. The average age of the 52 participants was 44. The affiliations of the participants who attended at least one workshop ($N = 51$) or attended all three workshops ($N = 18$) was as follows: Consultant (6%/0%), federal agency (14%/6%), state agency (20%/6%), municipal agency (4%/0%), academic institution (45%/83%), NGO (6%/6%), and other (6%/0%). The majority of the participants were from academic institutions, but a substantial fraction of participants that attended at least one workshop were from government agencies or NGOs.

4.2 Pre- and Post-Survey Analysis of Beliefs Regarding Models

We present results of the scales generated for the pre- and post-workshop surveys for the individuals that attended all three workshops ($N = 18$) in Table 1. Results for individual

Table 1 Beliefs regarding water models for participants who attended all workshops

Scale	Pre-Survey			Post-Survey			Comparison		
	N	Mean	SD	N	Mean	SD	Δ Mean	*t*-test score	Significance (2-tailed)
Participant's Prior Experience with Models (Cronbach's $\alpha = 0.88$)	18	2.94	1.07						
Beliefs about personal capacity to use and understand water models (Pre/Post-survey Cronbach's $\alpha = 0.89/0.93$)	18	3.08	0.94	18	3.83	0.89	0.75*	−3.18	0.01
Beliefs about usefulness of water models (Pre/Post-survey Cronbach's $\alpha = 0.89/0.79$)	18	4.04	0.97	18	4.85	0.25	0.81*	−3.45	0.00
Beliefs about accuracy of water models (Pre/Post-survey Cronbach's $\alpha = 0.83/0.76$)	17	3.21	0.78	17	3.00	0.86	−0.21**	0.92	0.37

* Significant at 99% confidence level

* Significant at <95% confidence level

questions in the surveys are tabulated in the Supplemental Information. The scales for the pre- and post-surveys have high values of Chronbach's alpha ($\alpha = 0.76$ to 0.93), indicating that all scales were statistically significant. The results for the index "Participant's prior experience with water models" in the pre-survey indicates that, on the whole, participants' self-evaluation of experience with models was "medium." Individual survey questions revealed that most participants have less experience applying models than analyzing model output. The results show that participants' beliefs regarding their capacity to use and understand models increased significantly between the pre- and post-survey. Answers to individual survey questions also demonstrated that not only did participants' knowledge of the WRSM and its associated software increased considerably, but also that their understanding of hydrologic and water resource systems models also increased.

The results for the scale "Beliefs about usefulness of water models" show that the scale mean increased from 4.04 to 4.85, a significant change at the 99% confidence level, indicating that, while participants believed models to be useful before the workshops, they are significantly more likely to believe this after the workshops. The results from the individual questions in this scale also show increases in beliefs about the utility of models occurred for both hydrologic and water resources systems models.

For the scale "Beliefs about accuracy of water models," Table 1 shows that participants' neither agreed nor disagreed that water models are accurate and no significant changes were observed in this scale pre- and post-workshop. The reasons for this result are unclear, especially given that participants' beliefs in the utility of models increased during the workshops. We speculate that the context and the specific words used in the questions in this scale were ambiguous, and if the questions were re-worded, we would have seen an increase in this scale and responses to the underlying questions. Before the workshop, participants' believed that models were accurate at the "medium" level, except for responses to individual questions regarding model abilities to predict the impacts of climate change, which indicated that participants' believed these models' predictive ability was substantially higher. The reasons for this result are also unclear, but we speculate that the emphasis on climate change impacts on water resources in the scientific and practitioner communities may have influenced participants' beliefs.

The regression results showed that two of the post-workshop scales were significantly negatively correlated with the scale "Participant's prior experience with water models," with coefficients of −0.63 ($p = 0.020$) and −0.49 ($p = 0.035$) for "Beliefs about personal capacity to use and understand water models" vs. "Participant's prior experience with water models" and "Beliefs about usefulness of water models" vs. "Participant's prior experience with water models," respectively. This result implies that participants with less prior experience tended to have greater confidence in their abilities to use and understand models and the utility of models, post-workshop. However, the results show that there was no significant correlation between "Beliefs about accuracy of water models" and "Participant's prior experience with water models." post-workshop beliefs in model accuracy and prior experience (slope = 0.05, $p = 0.23$). While independent demographic variables (age, education, gender, and affiliation) were included in all three regressions, none of the post-workshop beliefs on modeling were significantly correlated with the demographic variables (all p-values were greater than 0.15).

4.3 Water Resources Management Strategies

These results were determined for all of the participants in the third workshop ($N = 30$). The average and standard deviation of total additional water supply and gains in water use efficiency were 64 MCM/yr. and 21 MCM/yr., respectively (MCM = million cubic meters). Figure 2 shows the average and standard deviation for each water supply and demand strategy, in terms of additional flow, selected by the participants. The largest supply gains were obtained by repair of the Hermosillo distribution system and reuse of wastewater for recharging the aquifers used for the Hermosillo water supply. The largest gain associated with water use efficiency was for the agricultural sector. These three gains represented almost two-thirds of the total gains. However, while gains associated with desalination and the capacity of the Independencia Aqueduct were small, on average, the large standard deviation indicates that some participants chose large gains for these water supply options.

The average gains for increasing "El Molinito" storage and aqueduct capacity are relatively small; however, these gains represented 87% of the maximum allowable gain. Reuse of wastewater for industrial water use was also a relatively small average gain, especially when compared to the gain for reuse for aquifer recharge, but was close to the maximum allowable (92% of the maximum). Standard deviations for the "El Molinito" capacity increase and industrial water reuse were relatively small, indicating that most participants maximized or nearly maximized the gains associated with these two options.

The average gain for residential water use efficiency was substantially less than the gain for agricultural water use. This difference is partially related to the fact that agricultural demand, on average, was projected to be larger than residential use, but the average expected fractional increases in efficiency for agricultural and residential water use were 15% and 11%. However, the standard deviations for the efficiency for agricultural and residential water use were relatively large. Most participants chose substantial increases in efficiency for one, but not both of these sectors (data not shown here), apparently indicating that there was disagreement about which sector would be capable of demand reductions. The average gains for industrial water use efficiency were small relative to the other two sectors. However, this result reflects the fact that industrial use is predicted to be a relatively small fraction of overall water use.

The average water supply reliability for the participants' chosen management strategies over all scenarios was 94%. Figure 3 shows the average reliability over all of the participants' chosen strategies as a function of climate and development scenario. These results show that, although the reliability averaged over all scenarios is relatively high, substantially lower reliabilities were found for the more extreme scenarios. For example, for the "Hyper" development scenario and the two driest years, Historic Dry and Far Future Dry, the average reliabilities were 55% and 41%, respectively. This result may reflect that participants are willing to accept less reliability under these conditions or that they are less likely to believe that these conditions will actually occur. Whereas the standard deviations across participants for a given set of scenarios were relatively low (average coefficient of variation = 0.06), the standard deviations for the lowest reliability scenario combinations, Hyper-Historic Dry and Hyper-Far Future Dry, were 15% and 18%, respectively. These higher standard deviations indicate that there was a wide range of acceptable reliabilities for these scenario combinations.

4.4 Diversity of Participants' Selected Strategies

For the clustering analysis, the fraction of attribute-pairwise classifications with $F_{p\ <0.05}$ was 82% and the silhouette coefficient was 0.64. Both results indicate that the clustering was robust. The groupings resulting from the clustering are shown in Table 2, indicating three distinct groups (A, B and C), each of which represents roughly one-third of the participants. A fourth group (D) did not show significant differences between attributes and could not be assigned to groups A, B and C. The qualitative levels for the attributes that were statistically significant are shown for each grouping. To summarize, these groups can be characterized as A: high reliance on technology, optimistic with regard to impacts, and expectations of high reliability; B: high reliance on technology, pessimistic with regard to impacts, and expectations of medium reliability; and C: less reliance in technology, high reliance on water reuse and residential demand reduction, and willingness to accept lower reliability. These significant distinctions between groups indicate that substantial disparities exist between the workshop participants as to how to resolve water resources management issues in the RSB and its regional stakeholders.

The analysis of the groups' beliefs in modeling capacity, utility and accuracy is shown in Table 2. For the most part, there were significant differences in scale means between groups A, B and C. Group A tended to have greater confidence in their capacity to use and understand models and to believe that models were more useful and accurate. Differences between groups B and C were not as strong. The differences between group D and the other three groups were less significant; this is not a surprising result, since the variation in attributes and scale means

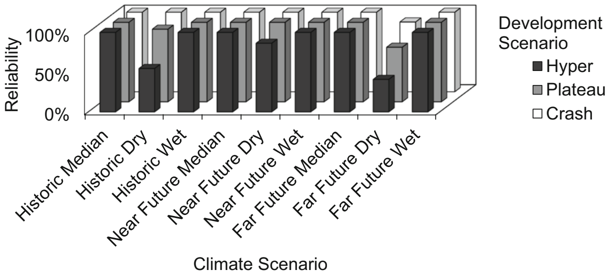

Fig. 3 Mean reliability (average daily supply/average daily demand) for water resources strategies as a function of climate and demand scenarios

Table 2 Results of clustering of participant attributes and post-workshop beliefs about modeling ($N = 30$)

Group	Attribute Characteristics	Fraction (Number) of Participants in Group	Mean Scales (Levels of Significance for Differences Between Means)		
			Beliefs about capacity to use and understand water models	Beliefs about usefulness of water models	Beliefs about accuracy of water models
A	high desalination, low reuse, high increase in agricultural water use efficiency, high increase in Independencia aqueduct, positive economic impact, high reliability	27% (8)	4.39 (B***/C***/D*)	4.89 (B*/C***/D*)	4.07 (B***/C***/D**)
B	high desalination, low reuse, high increase in agricultural water use efficiency, high increase in Independencia aqueduct, negative social impact, negative environmental impact, medium reliability	23% (7)	3.78 (A***/C***/D)	4.72(A*/C**/D)	3.11 (A***/C*/D*)
C	low desalination, high reuse, high increase in residential water use efficiency, low increase in Independencia aqueduct, low reliability	40% (12)	3.52 (A***/B***/D*)	4.22 (A***/B**/D*)	2.89 (A***/B*/D*)
D	other	10% (3)	3.99 (A*/B/C*)	4.60 (A*/B/C*)	3.39 (A**/B*/C*)

* Significant at 90% confidence level

** Significant at 95% confidence level

*** Significant at 99% confidence level

was much greater for group D than the other groups. It is interesting that the group that tended to rely on technology and was more optimistic about the outcomes of the water resources management strategies (group A) was also more optimistic about models.

5 Conclusions and Discussion

Three PM workshops were held in the Rio Sonora Basin, Mexico, in spring 2013. A model of the water resources system, consisting of a watershed hydrology model, a model of the water resources infrastructure, and groundwater models, was developed deliberatively in the workshops, along with scenarios of future climate and development. In the last workshop, participants used the final version of the model to select from supply-side and demand-side management strategies. The performance of the strategies was based on the reliability of meeting current and future demands at a daily time scale over a year's period. Participants were also asked to rate the economic, social, and environmental impact of their chosen strategies.

The selected water resources strategies and the associated, expected reliability varied widely among participants. Most participants (90%) could be clustered into three groups with roughly equal numbers of participants: A: high reliance on technology, optimistic with regard to impacts, and expectations of high reliability; B: high reliance on technology, pessimistic with regard to impacts, and expectations of medium reliability; and C: less reliance in technology, high reliance on water reuse and residential demand reduction, and willingness to accept lower reliability. The average water supply reliability for the management strategies over all of the climate and development scenarios was 94%. Although the reliability averaged over all scenarios is relatively high, a lower set of reliabilities were found for the more extreme scenarios. For the development scenario with the greatest increase in population and irrigated area and the two driest years, the average reliabilities were 55% and 41%, respectively. The wide range of strategies chosen and associated reliabilities indicate that there is a substantial degree of uncertainty in how future water resources decisions could be made in the region.

The number of workshop participants and the diversity in affiliation of the workshop participants declined, such that the majority of the participants who attended all three workshops represented academic institutions. The lack of breadth in participant affiliations and the small number of participants that attended all workshops and could introduce bias in the results, in terms of the changes in beliefs about models, choices of water resources management strategies, and the clustering of participants into distinct groups. The fact that 83% of those who attended all workshops were affiliated with academic institutions could be cause for concern in the results; however, the results for choices of management strategies and the clustering of participants into distinct groups indicate that there was a wide diversity of viewpoints. Furthermore, the affiliations on the third workshop, where the data was collected, were more diverse: 37% academic; 25% municipal, state or federal agency; 27% NGO; and 11% other.

Comments made during the workshop and in the surveys revealed that many participants found the richness of the dialog during the workshops was as important a value as was the outcome of the modeling. However, several aspects of the workshops could be improved. First, the decline in the number of participants implies that interest in the workshops could not be sustained or that participants were simply unwilling to commit to three events over three months and occupying a total of 17 h. Second, more time for reflection on the model results during the third workshop may have resulted in a richer discussion of how to move forward in resolving the water crises facing the RSB. We speculate that, for example, the disparities between the groups may have somewhat dissolved if a greater discussion of the model results and the participants' choices of management strategies had occurred. Third, because of the relatively low attendance by participants affiliated with government agencies in all workshops, it may be less likely that the workshop will influence government policy. In future workshops, strategies for recruiting and retaining a wider range of participants should be explored.

Acknowledgements This work has been partially supported by National Science Foundation award CBET 1014818. We acknowledge the excellent facilitation of the workshops by Ana Cristina Pacheco. Finally, we are indebted to the workshop participants for their time and energy.

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