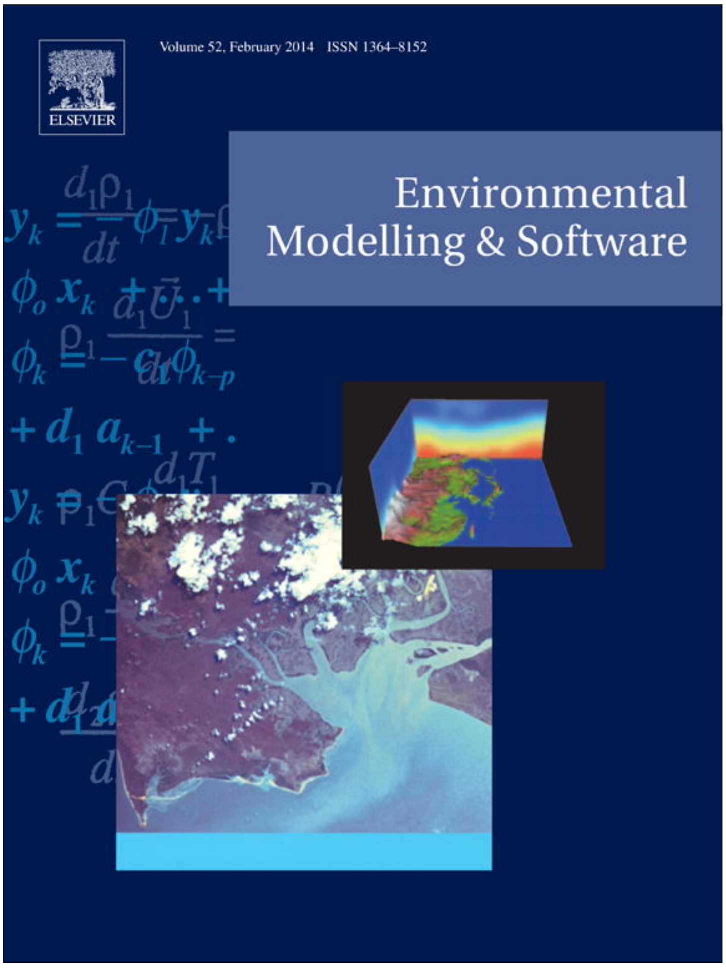
Volume 52, February 2014 ISSN 1364-8152
ELSEVIER
Environmental
Modelling & Software

Environmental Modelling & Software 52 (2014) 273–282

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

Exploring the application of participatory modeling approaches in the Sonora River Basin, Mexico

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A R T I C L E I N F O

Article history:
Received 30 July 2013
Received in revised form
1 October 2013
Accepted 3 October 2013
Available online 16 November 2013

Keywords:
Modeling workshop
Risk perceptions
Hydrologic modeling
Water quality modeling
Less-developed regions

A B S T R A C T

This study presents the results from evaluation of a hydrologic modeling workshop for 46 water resource decision makers in Hermosillo, Mexico. This region has serious, ongoing water quantity and quality problems. Our goals were to assess participants' perceptions of our workshop and associated hydrologic and water quality models and to learn whether it changed their perceptions of local water resource-related problems, causes, and solutions. We administered on-site pre-and post-workshop surveys to assess any changes and to collect evaluations of the workshop and models. A few about water quality problems changed significantly over the course of the workshop, but most measured perceptions did not. On average, participants rated the workshop highly and believed that the presented models could assist their future decision-making. These results could contribute to future watershed modeling workshop efforts.

1. Introduction

This paper presents the results of an assessment of a hydrologic and water quality modeling workshop conducted with water resource managers in the State of Sonora in northwest Mexico. The region has severe water quality and scarcity problems as well as significant water user conflicts. Our findings are particularly relevant for understanding the short term impacts of presenting locally-relevant water quantity and quality information and for modelers who want to share their models with managers to enhance their understanding of and ability to use such models.

Northwestern Sonora experiences significant climate variability causing drought and pluvial periods lasting from a few years to several decades (Sheppard et al., 2002). This climate variability makes it particularly challenging to operate and maintain water infrastructure. Future changes in precipitation forecasted by general circulation models predict a more arid climate (e.g., Diffenbaugh et al., 2008; Seager et al., 2007). These conditions would further reduce streamflows (Nohara et al., 2006) and soil moisture (Wang, 2005) worsening future droughts. Resultant impacts on local water users will vary depending on the local water infrastructure capacity (i.e. reservoirs, distribution systems, drinking water and wastewater treatment systems). The inability of Mexican water management agencies to adequately maintain existing water infrastructure systems makes significant future improvements seem unlikely (Pineda, 2006; Robles-Morua et al., 2009; Simonelli, 1987; Tortajada, 2003). This situation makes the region more sensitive to hydrologic shifts associated with climate change.

Hermosillo, the rapidly-growing Sonoran state capital, is particularly vulnerable. It depends on groundwater wells and surface supply from the Sonora River Basin (SRB) to its northeast (Fig. 1). Water from the coastal SRB aquifer that supplies Hermosillo's water is being extracted at an unsustainable rate (Guevara-Sanguines, 2006; Moreno-Vazquez, 2006). Water resource problems have become important regional policy issues. News reports on them appear almost daily (Gonzalez, 2009; Meza, 2009; Moreno, 2009; Montoya, 2010; Salazar and Pineda, 2010). These issues are exacerbated by the fact that the city's population has been increasing at an unsustainable rate of more than three percent per year (Consejo Nacional de Poblacion, 2008). For instance, a

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http://dx.doi.org/10.1016/j.envsoft.2013.10.006

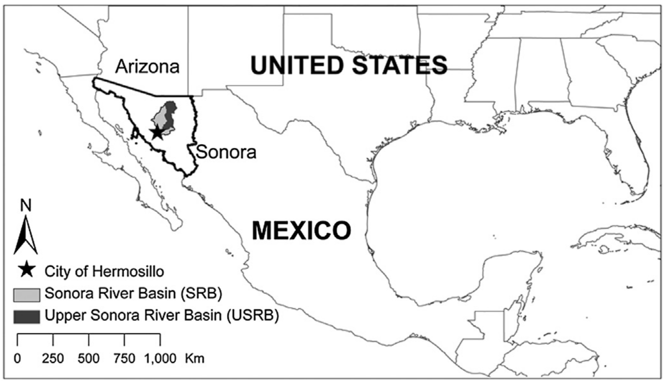

Fig. 1. Map showing the locations of the Sonora River basin (SRB), Upper Sonora River Basin (USRB) and the city of Hermosillo, Sonora, Mexico.

prolonged 1990s drought forced the city to impose severe water rationing (Eakin et al., 2007; Pineda, 2006).

Insufficient water supplies are causing conflict between the state's urban and agricultural sectors. In addition, the discharge of untreated wastewater into the SRB is causing significant water pollution and waterborne disease problems (Browning-Aiken et al., 2002; Ingram et al., 1995; Liverman et al., 1999; Robles-Morua et al., 2009, 2011). Concentrations of indicator pathogens have been found to exceed Mexican water quality standards downstream of at least two SRB communities (Robles-Morua et al., 2012b).

These water management challenges are further complicated by Mexico's regulatory framework. The Mexican National Water Commission (CONAGUA) allocates regional surface water rights and adjusts them annually based on water availability. The SRB is overseen by the Upper Northwest River Basin Council. It must approve substantial water resource management changes. Decentralization reforms resulted in the creation of river basin councils consisting of representatives from academia, federal and state water sectors, non-governmental organizations, and representatives of key water use sectors (Tortajada, 1998). National water law stipulates that river basin councils can develop and implement water management programs, including water infrastructure. However, few councils function effectively (Tortajada and Contreras-Moreno, 2005).

Sonoran municipalities manage their own water and sanitation with funding and technical advice from state and federal agency officials (Pineda, 2002; Simonelli, 1987). Many community-level drinking and wastewater treatment systems work poorly or not at all (Robles-Morua et al., 2011). Some communities have neither drinking nor wastewater treatment systems. Many communities suffer from periodic water shortages.

Our results are part of a long-term, multi-disciplinary project to assess risks associated with waterborne diseases in the upper Sonora River Basin (USRB), the largest sub-basin ($\sim$9,300 km^2) of the SRB. The project began with assessment of risk perceptions associated with wastewater contamination of water resources (Robles-Morua et al., 2011). We found that community members and government officials along the USRB frequently underestimated health risks associated with local water quality (Robles-Morua et al., 2011). Second, a fully distributed hydrologic model was developed to make streamflow predictions in space and time, given that the main stem of the USRB is ungauged (Robles-Morua et al., 2012a). The hydrology model employed a unique rainfall data assimilation procedure, since high resolution rainfall data was unavailable in the basin. Third, the synthetic streamflows generated with the hydrology model were incorporated into a surface water quality model, which was used to predict the transport of pathogens associated with wastewater discharges in the USRB (Robles-Morua et al., 2012b). To parameterize this water quality model, we estimated pathogenic loadings, die off rates and their uncertainty, and dilution effects related to varying streamflow regimes. Results indicated high probabilities that pathogen concentrations exceed fecal coliform standards along the main stem of the USRB.

This current paper reports the results of a participatory modeling workshop conducted to measure perceptions of the outputs of our USRB watershed models and modeling results. Our goals included assessing the value of a participatory modeling workshop for regional water resource managers and its ability to change their perceptions of water-related problems, causes, and solutions.

The most effective water resource decision-making includes water managers, officials, community members, researchers from academic institutions, and water consultant professionals. As described by Reed et al. (2010) and Pahl-Wostl (2006), participation in such decision-making fora may help individuals learn about underlying problems, including their causes and solutions.

With this in mind, this study presents results from data collected in a participatory modeling workshop conducted with major SRB decision makers. It focuses on individual learning and developing methods that can be used in future research as delineated in Rouwette and Vennix (2003) and Rouwette et al. (2002). We report on the following objectives of the study: (a) to determine whether water resource modeling can be useful to local water managers and (b) to determine if the modeling workshop changed participants' perceptions of regional water quantity and quality problems.

2. Participatory modeling

Modeling is an important tool for conceptualizing the inherent complexity of natural systems (Chapra, 1997; DePinto et al., 2004; Smith-Korfmacher, 1998; Korfmacher, 2001). It can also inform and support integrated watershed management decisions (Dietz et al., 2004; Ewing et al., 2000; Gaddis et al., 2010; Parker et al., 2002; Voinov and Gaddis, 2008). It also has the capacity to integrate knowledge to develop tools that can be used to help understand management tradeoffs (Kelly (Letcher) et al., 2013; Kragt et al., 2011). As Tsouvalis and Waterton (2012) note, participatory modeling that includes non-experts is a growing trend. This type of modeling, also referred to as cooperative modeling, collaborative modeling, or mediated model-building, refers to the process of collaboratively constructing a model that is a common representation of a complex natural resources management system (Barreteau et al., 2007; Jones et al., 2008; Van den Belt, 2004; Voinov and Gaddis, 2008). Participatory modeling can assist in collective decision-making for a broad range of resource management issues (e.g. Barreteau et al., 2007; Beall and Zeoli, 2008; Jones et al., 2008; Stave, 2002; Van den Belt, 2004), including water resource management (Bots et al., 2008; Castelletti and Soncini-Sessa, 2006; Cockerill et al., 2006; Gaddis et al., 2010; Langsdale et al., 2009; Korfmacher, 2001; Van Eten et al., 2002). The rationale underlying participatory modeling is that, by gathering and integrating diverse participant knowledge and viewpoints and building trust, a collective management vision can be created and adapted to changing conditions (Korfmacher, 2001; Reed, 2008).

Participatory modeling has many variations. Hare (2011), Voinov and Bousquet (2010), Lynam et al. (2007), Korfmacher (2001), Pahl-Wostl (2002), Jakeman and Letcher (2003) and Van den Belt (2004) provide an overview, describing variations based on the level of stakeholder involvement. Voinov and Bousquet (2010) and Hare (2011) provide descriptions of the different stages of a participatory modeling process.

We distinguish between four broad types of participatory watershed modeling approaches. The first type is "Model Development", where participants are involved from the beginning in the development of a perceptual model, including model selection, development, parameterization and calibration (Gaddis et al., 2010). It entails a continuous and iterative process where the participants may interact periodically through meetings or workshops (see Castelletti and Soncini-Sessa, 2006; Videira et al., 2009 for case studies). The second type is the "Model Setup, Parameterization and Calibration" approach, which is often used when the decision to use a certain model has already been made (see Metcalf et al., 2010; Voinov and Gaddis, 2008; White et al., 2010 for case studies). One of the main goals of this type of approach is to transfer the model usage knowledge from experts to practitioners. These activities may include determining the model parameterization or calibration procedures needed to accurately represent existing conditions. Lippe et al. (2011) describes a different version of this type of participatory modeling in the sense that participants' knowledge and perceptions were measured and used to define model parameters. However, participants did not work with the model directly (Lippe et al., 2011).

The third type is the "Model Output Analysis" approach, which includes asking participants to provide feedback about modeling results produced by experts (Costanza et al., 2002; Stave, 2002). The primary goal is knowledge sharing, obtaining perceptions of model results, and feedback for future modeling efforts. This approach exposes participants to new model-generated information and to evaluate model selection (see Hare et al., 2003 for case studies). Finally, the fourth type is the "Scenario Building" approach, consisting of presenting scenarios of interest to participants (Craps et al., 2004; Guo et al., 2001). This approach can be a useful first step before participatory approaches with higher levels of involvement or at the end of a project where scenario evaluation is the main objective. This approach can be used to evaluate existing models that have already gained participant trust. In a continuous process, this type of project could be short-term, with more long-term discussions of model selection development (Otter et al., 2004).

A number of authors have assessed the factors contributing to the success or failure of participatory modeling processes, recommending best practices such as having transparent modeling processes, working with small groups in flexible planning processes, engaging participants early and often, creating participant groups representative of the larger community, recording discussions for analysis, and measuring the performance of the participatory modeling process (see Bots et al., 2008; Korfmacher, 2001; Matthews et al., 2011; Pahl-Wostl, 2002; Van den Belt, 2004; Videira et al., 2009; Voinov and Gaddis, 2008). More recently, Leenhardt et al. (2012) evaluated participatory modeling approaches as a source of quantitative indicators for decision makers. The authors concluded that it is important to customize raw model outputs so that the results are relevant and meaningful for decision makers. However, few studies include participant assessment of the processes.

In addition, little peer-reviewed work has been done to systematically and quantitatively assess the success or failure of participatory modeling approaches, particularly in less developed regions. Cockerill et al. (2004) identified attitudes towards models in general and then evaluated attitudes regarding the application of the Middle Rio Grande water resources planning model. Their findings included that the 61% of surveyed respondents did not believe models to be too complex for them to understand. Most stated that their level of trust in a model would depend on who designed it. Overall respondents had positive attitudes toward models with 80% believing that the use of models can assist decision makers (Cockerill et al., 2004). Fokkinga et al. (2009) found differences between participants' pre- and post-process conceptual models and argued for the importance of objective measures of participant learning. Several other studies evaluated the impact of models using qualitative approaches (e.g. Costanza and Ruth, 1998; Hare and Pahl-Wostl, 2002; Ison and Watson, 2007; Medlener et al., 2007; Metcalf et al., 2010). Vrana et al. (2012) suggest a new method of aggregation aimed at developing indicators that can help measure the degree of decision maker agreement related to model outputs. Recent work has applied human computation to participatory water resources planning and management processes (e.g. Fraternali et al., 2012) and Bayesian belief networks (e.g. Aguilera et al., 2011).

Despite the increasing recognition and popularity of participatory modeling approaches, important knowledge gaps remain regarding their impacts on participants (Voinov and Bousquet, 2010). Minimal work has been published that rigorously measures participant perceptions of modeling processes or process impacts on participants (Jones et al., 2008; Pahl-Wostl, 2002; Rouwette and Vennix, 2003; Rouwette et al., 2002, 2011; Van den Belt, 2004). Much of the literature treats each participatory modeling case as a unique process where comparison is impossible (Cockerill et al., 2006; Hare, 2011). While some work has used quantitative pre- and post-surveys to assess change (see, for example, Rouwette and Vennix, 2003; Rouwette et al., 2002, 2011), these types of surveys have not been used to assess participatory modeling related to developing world water resource management. We therefore used pre- and post-surveys that could contribute quantitative mechanisms to measure participatory modeling impacts on participants and to collect participant evaluations of the modeling processes.

3. Research design

We present the results of the use of surveys to assess an exploratory participatory modeling workshop for water resource managers in Hermosillo, Mexico. The workshop was designed to assess the value to participants of hydrologic and water quality models of the USRB and to learn whether providing the participants with new water-related information (through the models) changed their perceptions of basin water problems. Our workshop falls under the "Model Output Analysis" type of participatory modeling described previously. This approach is consistent to what Voinov and Bousquet (2010) describe as "extractive use" where knowledge, values or preferences are extracted by a modeler who needs to better understand a complex system prior to diagnosing a problem. This type of participatory modeling approach is "consultative in nature, asking for input on definition and validity, but without extensive work between stakeholders and/or with the organizing team on model construction" (Hare, 2011; pg. 391). In our case, we are using the present study to lay the groundwork for long-term participatory modeling activity in the SRB.

We used a fully-distributed hydrologic model to simulate temporally- and spatially-distributed, precipitation-driven USRB streamflows. Model simulations were conducted using the Triangulated Irregular Network (TIN)-Based Real-time Integrated Basin Simulator (tRIBS, Ivanov et al., 2004; Vivoni et al., 2007). This physically-based hydrologic model is capable of making distributed stream flow predictions in ungauged river basins by relying on parameters that can be directly connected to quantifiable landscape properties. This capability is further enhanced by capturing the spatial distribution of the landscape variation in soils, vegetation, topography, and depths to water table and bedrock.

The water quality model simulates the transport of pathogens emanating from wastewater sources as a function of the synthetic flows generated by the hydrologic model. The water quality model is based on QUAL2K, a one-dimensional hydrodynamic surface water quality model developed by Chapra et al. (2008). The model integrates inputs from point and non-point sources to determine impacts on water quality in receiving water bodies, including the fate and transport of generic pathogens. Both the hydrologic and water quality models were developed for the USRB and are part of our research studies ongoing since 2006 (Robles-Morua et al., 2009, 2011, 2012a,b).

3.1. Workshop

Seventy-five decision makers involved in water quantity and quality management in the USRB were invited to participate. We focused on selecting individuals whose responsibilities included water or water-related social welfare so that the workshop would be meaningfully related to their work. A list of potential participants was created based on interviews with officials from the State of Sonora Water Commission and the regional office of CONAGUA. These officials oversee and interact with the important water users and decision makers, in addition to the personnel within their agencies involved with issues of water quantity and quality. Meetings with the manager of the Upper Northwest River Basin Council provided an additional list of USRB representatives that work closely with water agencies and the basin council. Personalized invitations were sent via email two months prior to the workshop. A reminder email was sent and a written invitation was delivered in person one week before the May 2010 workshop.

Forty-eight of the 75 invited participants attended the six hour workshop. Table 1 shows workshop participant organizational affiliations. Because of the nature of their work, the participants were particularly well-educated. All had at least an undergraduate degree and 40% had graduate degrees. As indicated by the demographic information from the pre-survey, the areas of expertise represented by these participants included water resources management, hydrometeorology, water quality control, public health, groundwater management, water-related infrastructure construction and maintenance, and natural resource management. Seven participants had job duties that included hydrological modeling.

Forty-six participants completed both on-site pre- and post-surveys (two of the original 48 participants left before the post-survey was administered). The surveys had codes that allowed us to link individuals' pre- and post-surveys. All results are provided for those 46 participants. Participants completed and returned the post-survey onsite. We also collected qualitative data; for example, the pre-survey contained one open-ended question that asked participants to list any other water related problems they considered that we did not have in our list of close-ended questions. Similarly, the post-survey contained three open-ended questions that asked participants to express in their own words: 1) which parts of the modeling work presented they had the least amount of confidence, 2) comments to add about the workshop, and 3) their willingness to participate in future workshops aimed at developing and applying computational models as tools for assisting watershed management decision-making processes. In addition to these open-ended questions, feedback was also obtained through notes and audio recordings of the discussions that took place during the workshop.

Table 1
Organizational affiliations of workshop participants ($N = 46$).

Affiliation	Fraction of participants
Federal government	9%
State government	35%
Watershed councils	20%
Universities	26%
Consulting firms	11%

The workshop agenda included:

(1) introductions and a presentation on workshop objectives;
(2) pre-survey completion;
(3) a brief background talk about participatory modeling;
(4) a presentation on hydrological models, the relative advantages and disadvantages of different models, and a summary of our hydrological model;
(5) a presentation on surface water quality modeling, different models and their advantages and disadvantages and a summary of our surface water quality model;
(6) a presentation of our USRB hydrological and surface water quality model results;
(7) a discussion session with comments, questions and answers about the models and results and the value of water resource modeling;
(8) post-survey completion; and
(9) a post-workshop dinner.

Hydrological modeling results focused on streamflow forecasts in space and time using comparisons of data from Mexican sources and remote sensing products. A comparison between the rainfall forcing data sets allowed us to illustrate the limitations of available sources of data (local and regional ground observations) and knowledge gaps in terms of our streamflow predictions in important northern regions of the basin with proposed reservoirs. Maps of the spatially distributed streamflows were presented using forcing from the ground observations. The maps were then used to discuss the lack of available stations and the problems this causes in the adequate representation of rainfall spatial variability in this region. In addition, we showed the results of routing the streamflow from every sub-basin to the main outlet where it was compared to the few available stream measurements. Additional details on the distributed hydrologic modeling results are described in Robles-Morua et al. (2012a).

Water quality modeling was conducted to illustrate the impact on surface water quality associated with the discharge of untreated or poorly treated wastewater from three of the largest rural communities in the USRB. During the workshop, we presented how we estimated wastewater pathogen loadings and in-situ pathogen die-off rates for the three selected sites. Furthermore, we described the methods for collecting samples and for measuring river flows in order to make estimates of the pathogen loads and die-off rates in the river. The results presented focused on illustrating the typical pathogen concentrations in the river under low and high streamflow conditions. Plots of pathogen concentrations over distance in the three sites indicated the areas in the river where pathogen concentrations exceeded Mexican water quality standards. Additional details on the water quality modeling results are presented in Robles-Morua et al. (2012b).

3.2. Surveys

This study presents the results of the quantitative information collected during the workshop described in the previous section, collected using pre- and post-surveys in participants' native Spanish. The use of comparisons of pre- and post-surveys has been applied to investigate behaviors and attitudes on a broad range of topics (Bernard, 2005; Neuman, 2005). For example, in the US, Halvorsen (2003) applied a similar approach to assess the effects of public participation on a series of land management meetings in a national forest. Similarly, Viswanathan et al. (2004) conducted a study to assess the impact of community capacity-building strategies to improve health-related issues. In less developed regions, pre- and post-surveys have been used to analyze the impacts of family planning communication campaigns (Kane et al., 1998; Lettenmaier et al., 1993), vaccination campaigns (McDivitt et al., 1997), AIDS risk reduction programs (Antunes et al., 1997; Myhre and Flora, 2000). To our knowledge, no participating modeling work evaluating the success or failure of a process from participant's viewpoints, using pre- and post-surveys, has been published.

The Spanish language pre- and post-surveys used in this study were designed to measure changes in water related risk perceptions and to evaluate workshop's value to participants. Both surveys used five-point Likert scales, where 1 = strongly disagree, 2 = disagree somewhat, 3 = neither agree nor disagree, 4 = agree somewhat, and 5 = strongly agree. The pre-survey included standard demographic questions, while questions about perceptions of basin-wide water-related problems, the value of water-related modeling, and participant comfort with models were repeated in the pre- and post-surveys. The post-survey also included questions asking participants to assess workshop quality.

3.3. Data analysis

Analysis was conducted with SPSS™ software. Factor analysis (Kim and Mueller, 1978), with a cutoff value of 0.5, was used to determine the interdependency between items (questions) in order to determine which items could be grouped together into scales. Usage of scales constructed of multiple question items allows the construction of complex variable measures. In cases where a specific item did not meet the factor analysis cutoff value, those questions were removed from the analysis. Chronbach's alpha (α) coefficients were calculated to evaluate the reliability of each scale. This widely used coefficient of reliability measures the degree to which survey responses combine to measure one coherent variable (Halvorsen, 2003; Neuman, 2005). Values of Chronbach's alpha increase as the inter-correlations among the items in each scale increase. Typically, an α value greater than 0.6 indicates that a scale is reliable.

In addition, we conducted a one-way analysis of variance (ANOVA) assessing significant item and scale changes in the pre- and post-surveys. The one-way ANOVA test calculates the F statistic and the p value. The former is used in the calculation of the significance or p value and not used here for any interpretation. The p value measures the significance of the differences between mean item responses to the pre- versus post-surveys. These statistics were computed at the 5% and 10% significance level. A low p value means that the difference between the items in the scale is statistically significant. The items, scales, means, Chronbach's alphas, and results from the ANOVA tests are presented in Table 2 through 4.

The qualitative data collected using the open-ended questions were carefully coded, using standard qualitative analysis methods in order to identify common answer patterns and quantify the number of interviewees providing these answers to each question (as described in Robles-Morua et al., 2011). Individual files containing the qualitative responses to each question were analyzed separately.

4. Results

All responses to individual question items or scaled items are presented as mean group responses on a five point Likert scale. The scaled items all had strong Chronbach's alphas of 0.6 or greater.

Table 2
Items, scales, and mean participant responses regarding pre-workshop beliefs about existing watershed management plans and modeling as tools that can assist decision makers. Chronbach's alpha (α) are reported for each scale.

Scales and items	Mean response[a]	N[b]
Self-reported experience developing watershed management plans and comfort with models. (α = 0.720)	3.05	41
I have a lot of experience in the development of watershed management plans.	2.26	42
I am familiar with mathematical models used to assist the development of watershed management plans.	2.95	44
I feel capable of being able to work with mathematical models.	3.98	43
I have worked with researchers and government representatives in the development and/or application of mathematical models.	3.05	43
Beliefs about the quality of existing regional watershed management planning. (α = 0.649)	1.93	41
Only government institutions should be responsible for developing watershed management plans.	1.66	44
Existing policies and watershed management plans are working properly.	1.88	43
The current process to develop watershed management plans is transparent.	2.24	41
Beliefs about modeling's value as a tool to assist in the development of watershed management plans. (α = 0.509)	4.62	44
The use of mathematical models is an important tool to represent and simplify natural processes.	4.80	44
The results of mathematical models can provide important information to support decision making.	4.66	44
I trust in the results of studies that apply mathematical models at the watershed scale.	4.41	44

[a] Responses are based on a five-point Likert scale, where 1 = strongly disagree; 2 = disagree somewhat; 3 = neither agree nor disagree; 4 = agree somewhat; and 5 = strongly agree.
[b] N indicates the number of participants responding to statement. Responses of "don't know" are designated as missing values.

4.1. Beliefs about existing watershed management plans and self-reported experience working with models

As shown in Table 2, on average, participants disagreed somewhat with the statement that they had experience in developing watershed management plans (2.26) and agreed somewhat that they felt capable of working with mathematical models (3.98). They disagreed somewhat that existing watershed management plans were working properly (1.88). They also disagreed somewhat that the current watershed management planning process should be conducted only by government agencies (1.66) and that existing processes were transparent (2.24). Finally, they agreed strongly that modeling is a valuable tool to assist in the development of watershed management plans (4.62). On average, participants were not particularly experienced or comfortable with watershed modeling (3.05). They did not believe that USRB watershed management planning is currently of high quality (1.93).

4.2. Changes in water-related risk perceptions

The mean responses to scales are shown in Fig. 2 and individual items comprising each scale are presented in Table 3. Together, this information provides a comparison between participant's water-related beliefs before and after the workshop. Participants agreed somewhat that the USRB had water quantity problems. These beliefs did not change significantly before and after the workshop

Table 3
Comparisons of pre- and post-survey item and scale means. F statistics and *p* values indicate significance of differences between mean responses pre- and post-surveys. Chronbach's alpha (α) are reported for each scale.

Scales and items	Pre-workshop		Post-workshop		F Statistic	*p* value[c,d]
	Mean response[a]	N[b]	Mean response[a]	N[b]		
Beliefs regarding water quantity problems in the basin scale (pre-survey: $\alpha = 0.739$; post-survey: $\alpha = 0.684$)	3.50	45	3.64	41	0.379	0.540
In the Rio Sonora basin, there is not enough water for all users.	3.46	46	3.64	42	0.458	0.500
In the Rio Sonora basin, agricultural activities have problems due to the lack of water.	3.63	46	3.86	42	0.607	0.438
In the Rio Sonora basin, ranching activities have problems due to the lack of water.	3.48	46	3.57	42	0.104	0.748
Beliefs regarding basinwide water quality problems scale (pre-survey: $\alpha = 0.767$; post-survey: $\alpha = 0.805$)	3.84	42	4.18	38	3.923	0.051[c]
In the Rio Sonora basin, water quality is inadequate.	3.24	45	3.67	42	3.124	0.081[c]
In the Rio Sonora basin, we have public health problems due to water quality problems.	3.17	46	3.79	42	5.625	0.020[d]
In the Rio Sonora basin, it is important to identify locations at high risk of surface water quality problems.	4.51	45	4.74	42	1.414	0.238
In the Rio Sonora basin, if we don't understand the relation between water quantity and quality, we cannot properly manage the watersheds.	4.57	46	4.71	42	0.751	0.389
Beliefs about the water-related impacts scale (pre-workshop: $\alpha = 0.704$; post-workshop: $\alpha = 0.817$)	4.29	41	4.36	40	0.226	0.635
I am worried because economic development in the basin cannot be sustained given the available water resources.	3.93	46	4.10	41	0.386	0.536
I am worried because water scarcity problems could cause public health problems.	4.18	45	4.35	41	0.440	0.509
I am worried about droughts that may affect the population in the future.	4.63	46	4.63	41	0.000	0.985
I am worried because surface water in the Sonora River could become contaminated and unusable for swimming.	4.02	46	3.85	40	0.373	0.543
I am worried because groundwater could become contaminated due to the pollution of the river water.	4.39	46	4.39	41	0.000	0.996
Beliefs about causes of basin water problems scale (pre-survey: $\alpha = 0.662$; post-survey: $\alpha = 0.614$)	3.55	43	3.54	40	0.007	0.934
We do not have adequate infrastructure to use available water resources.	4.46	46	4.34	41	0.269	0.605
Water quality problems are related to the pollution derived from the mining industry.	3.80	46	3.78	41	0.010	0.919
Domestic wastewater and garbage are the main causes of water quality problems.	3.63	46	3.60	42	0.020	0.887
Agricultural activities are the main cause of water quality problems.	3.18	45	3.17	42	0.002	0.968
Ranching activities are the main cause of water quality problems.	3.00	46	3.02	42	0.008	0.931
Beliefs about poor water quality causing public health problems scale (pre-survey: $\alpha = 0.508$; post-survey: $\alpha = 0.844$)	3.40	44	3.60	40	1.10	0.297
Domestic wastewater and garbage are the main causes of public health problems.	3.28	46	3.48	42	0.545	0.462
Public health problems are related to surface water quality in the river.	3.41	46	3.60	42	0.544	0.463
Public health problems are related to drinking water quality.	3.68	46	3.79	42	0.775	0.381

[a] Responses are based on a five-point Likert scale, where 1 = strongly disagree; 2 = disagree somewhat; 3 = neither agree nor disagree; 4 = agree somewhat; and 5 = strongly agree.
[b] N indicates the number of participants responding to statement. Respondents of "don't know" are designated as missing values.
[c] significant at$<$0.10.
[d] significant at$<$0.05.

(3.50 and 3.64, respectively). However, some of their beliefs about water-related public health problems did change significantly. They were more likely to agree that these problems existed after participating in the workshop (pre-survey 3.17 and post-survey 3.79, $p = 0.020$). They were also more likely to believe that the basin had water quality problems after the workshop than before (3.84 versus 4.18), but this difference had p value slightly exceeding 0.05 ($p = 0.051$). Participants were somewhat worried about a variety of basin water scarcity and quality problems, but these beliefs did not change significantly before and after the workshop (4.29 versus 4.36). They agreed somewhat with our statements about the causes of these problems and these beliefs remained nearly the same before and after the workshop (3.55 versus 3.54).

4.3. Model and workshop evaluation

The participants' assessments of the hydrological and surface water quality models, the data upon which they were based, and the workshop within which they were presented are summarized in Table 4. The overall model assessment scale mean was 4.34. They consistently agreed somewhat or strongly that model results were useful, and that their presentation was clear and trustworthy (Hydrological model: 4.69, 4.43, 4.05; surface water quality model: 4.45, 4.38, 3.92). They also agreed somewhat that the results were realistic (4.12).

4.4. Feedback obtained from open-ended questions and during the workshop discussion

Participants were asked about their confidence in the models. Twenty-eight of the forty-eight participants answered this question. Four of these (14%) stated that they had no concerns. Twelve (43%) were concerned about the quality of forcing data used in the hydrology model. Five (18%) expressed concerns about the quality of the data obtained from Mexican water government agencies. Nine (32%) said that more details on the modeling runs were

Table 4
Workshop assessment scale, items and mean responses. Chronbach's alpha = 0.811, $N = 37$.

Model assessment scale (mean = 4.34)	Mean response[a]	N[b]
The results of the hydrological model (tRIBS) presented in this workshop are useful.	4.69	42
The presentation of the hydrologic results (tRIBS) was clear.	4.43	42
The data used to run the hydrologic model (tRIBS) are trustworthy.	4.05	40
The results of the surface water quality model (pathogen transport) (QUAL2K) presented in this workshop are useful.	4.45	42
The presentation of the surface water quality model results (QUAL2K) was clear.	4.38	42
The data used to run the surface water quality model (QUAL2K) are trustworthy.	3.92	38
The modeling results presented in this workshop can give realistic information of what occurs in the Sonora River Basin.	4.12	41

[a] Responses are based on a five-point Likert scale, where 1 = strongly disagree; 2 = disagree somewhat; 3 = neither agree nor disagree; 4 = agree somewhat; and 5 = strongly agree.
[b] N indicates the number of participants responding to statement. Respondents of "don't know" are designated as missing values.

necessary in order to assess model quality. Other concerns focused on the hydrological model parameterization, in particular how the saturated hydraulic conductivity was estimated. When we asked participants to provide additional comments about the workshop, twenty-three of the forty-eight participants responded to this question. A majority of the participants (52%) stated that the workshop was high quality and thanked the organizers for conducting it. Three (13%) of the participants said that it was motivating them to learn more about modeling and model application. Four (17%) said that they highly valued the opportunity to bring together decision makers and managers from multiple agencies. Two (9%) participants said that the workshop went well but would have liked more time to work with the models.

The last questions of the post-survey asked participants if they were willing to participate in future workshops to further develop and apply water resource modeling tools. Thirty-eight of the forty-eight participants responded; all stated that they would like to participate again if invited.

During the discussion session of the workshop, several participants expressed their concerns or initiated a discussion revolving around topics mentioned by the organizing team during the earlier stages of the workshop. The results presented here are highlights of the discussion that took place. A number of participants expressed concerns regarding the quality of Mexican government data used in the models. Much discussion focused on the feasibility of using the models in other Sonoran river basins. Representatives of several different watershed councils expressed a desire for the extension of the models to additional watersheds, leading to a discussion of what data is available for other river basins. This discussion was followed by an update on the installation of new climatological instruments. A comment about groundwater extraction being missing from the model led to a discussion of whether data was available to be able to quantify groundwater extractions. Participants also asked about post-workshop access to the models and presentations.

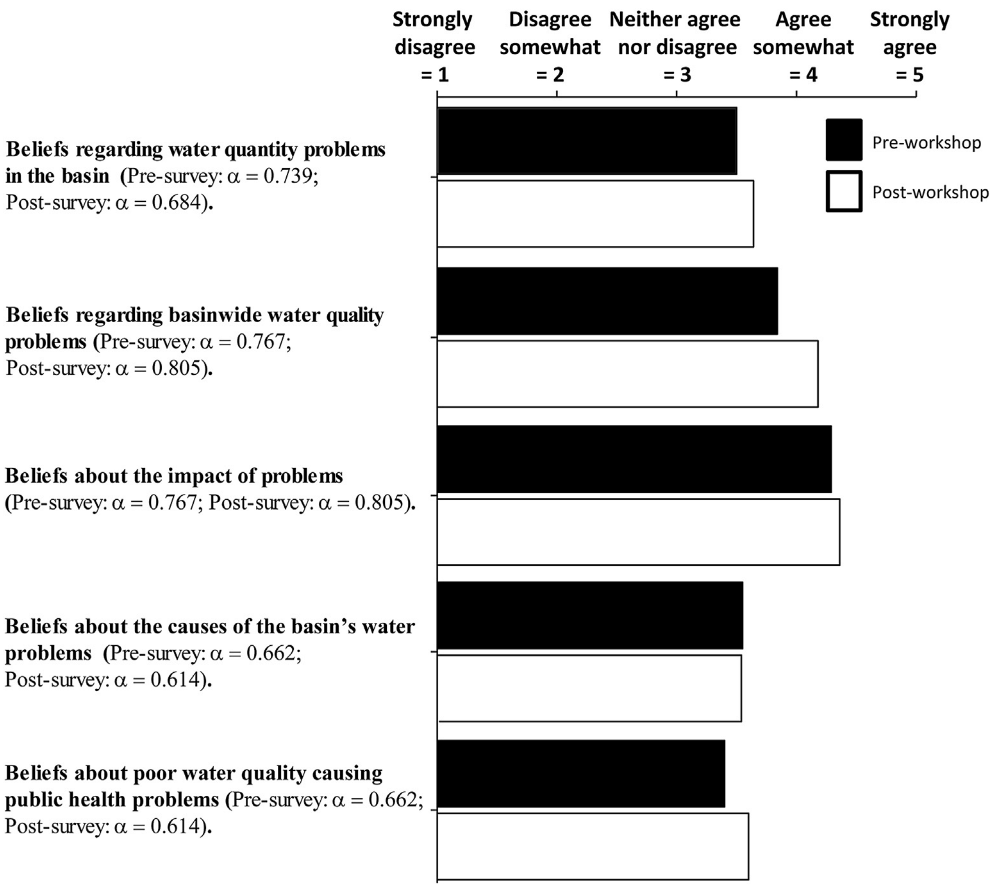

Fig. 2. Score averages for the five scales generated for comparison between the pre- and post-surveys. Responses were based on a five point Likert-scale (x-axis). Items comprising each scale are presented in more detail in Table 3.

5. Discussion

Our results indicate that participants were somewhat likely to agree that the models were clear, trustworthy, and useful. This finding is consistent with other research that found participants evaluated presented models as trustworthy (Barraqué et al., 2004; Cockerill et al., 2004; Van den Belt, 2004; Voinov and Gaddis, 2008). Cockerill et al. (2004), Bots et al. (2008) and Dietz et al. (2004) also found that participants assessed workshop models as useful. Our results regarding participant knowledge gained in our participatory modeling process are consistent with those of Cockerill et al. (2004, 2006). For example, Cockerill et al. (2004) reported that 61% of participants found the models accessible while 77% believed that their models could effectively inform interested publics. However, prior literature (e.g. Hare, 2011; Tippett et al., 2005; Webler et al., 2011) has shown that participant trust in model results does not necessarily lead to model adoption. Related issues for the USRB include participants' concerns about data quality.

Our findings regarding participant critiques of existing management plans and planning processes may be attributable to the fact that no Sonoran watershed basin councils have released publicly available documents regarding their watershed management decision-making. This result is consistent with Pineda's (2002) and Tortajada's (2003) findings that Mexico's water management decision-making continues to be highly centralized and closed to outside scrutiny.

In the course of our workshop, participants generally became significantly more likely to agree that the basin had water quality, but not with regard to water quantity problems. The greater change in water quality-related beliefs may have been because the participants had previously worked more with water quantity management than water quality problems (Robles-Morua et al., 2011). The lack of publicly-available information on Mexican water quality problems may also contribute to the change. Government-collected water quantity data is easily accessible, whereas water quality data access has to be requested through the Mexican Governmental Transparency Act leading to lengthy wait times (Instituto Federal de Acceso a la Información Pública, 2008). In addition, regional media frequently covers water scarcity-related issues (Gonzalez, 2009; Meza, 2009; Moreno, 2009; Montoya, 2010), but rarely, if ever, water quality-health issues.

Not all beliefs regarding water quality changed over the course of the workshop. For the most part, responses to statements associated with water quality problems did not change in cases where participants already strongly agreed with the statements. This result implies that participants were already quite concerned about some water quality problems before attending the workshop, making it unlikely that they could become more concerned. There were no significant changes in agreement with statements about causes of water quality problems before and after the workshop. For example, information presented during the workshop emphasized problems associated with domestic wastewater contamination, yet there was no significant increase in beliefs that this contamination source is important. This result may be attributed to lack of knowledge of connections between poorly treated wastewater and water quality degradation, a finding that resonates with Robles-Morua et al.'s (2011) conclusions regarding beliefs regarding the source of water quality problems in the USRB. Finally, participants' beliefs that water quality problems can cause public health problems changed significantly after participating in the workshop. This is probably due to some specific information presented in the workshop, including our finding that pathogen concentrations exceeded water quality standards.

Participants viewed inadequate water-related infrastructure as one of the major causes of regional water challenges. This was consistent with the findings of other researchers working in Mexico and other less developed countries (Tortajada, 2003; Eakin et al., 2007; Salazar and Pineda, 2010).

It is important to acknowledge that the majority of workshop participants were government agency staff, limiting our ability to draw conclusions about applicability to a broader regional public. In addition, analysis of the model output was the only form of participation during the workshop. We also acknowledge that our group size was relatively large (75 participants), which goes against Videira et al.'s (2009) recommendation that participatory modeling exercises be conducted in small groups. Nonetheless, all participants wanted to participate in future workshops and many were willing to participate in more time consuming, hands-on workshops.

6. Conclusion

Participant enthusiasm for our workshop indicates that longer, more intensively participatory efforts might also succeed in the region. However, it is important to note that our participants were quite well-educated. Participatory modeling with a broader regional public with less education might be less successful. While our pre- and post- survey results show that participant beliefs changed in only limited ways, they did demonstrate that change was possible even after a short workshop. Because this change was only assessed on the same day of the workshop, we do not know if this change was long lasting. However, our findings do indicate that watershed models could be helpful to Sonora water management decision makers and that a workshop such as ours can be a valuable mechanism to introduce them to the models. Our work also suggests that the value of participatory modeling is not limited to the industrialized world – it can be useful within relatively poor countries like Mexico.

Acknowledgments

We thank the three anonymous reviewers for their many helpful comments on this manuscript. We gratefully acknowledge the support of the Mexican federal government of the first author through a CONACYT PhD fellowship. This material is based in part upon work supported by the National Science Foundation under Grant Numbers CBET-1014818. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. We also acknowledge the support from Dr. Jose Luis Moreno and the Colegio of Sonora for providing access to their facilities. We are grateful for support from the Departments of Civil and Environmental Engineering and Social Sciences at Michigan Technological University, the School of Earth and Space Exploration at Arizona State University and the Department of Water and Environmental Science at the Technological Institute of Sonora. The assistance of Mrs. Cara Shonsey and Mr. Richard Vendliski in conducting the QUAL2K and tRIBS simulations is acknowledged as well.

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