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Perceptions of water conditions and management in the Sonora River Basin, Sonora, Mexico

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PERCEPTIONS OF WATER CONDITIONS AND MANAGEMENT IN THE SONORA RIVER BASIN, SONORA, MEXICO

By:

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Abstract:

The effects of climate change are expected to be very severe in arid regions. The Sonora River Basin, in the northwestern state of Sonora, Mexico, is likely to be severely affected. Some of the anticipated effects include precipitation variability, intense storm events, higher overall temperatures, and less available water. In addition, population in Sonora, specifically the capital city of Hermosillo, is increasing at a 1.5% rate and current populations are near 700,000. With the reduction in water availability and an increase in population, Sonora, Mexico is expected to experience severe water resource issues in the near future.

In anticipation of these changes, research is being conducted in an attempt to improve water management in the Sonora River Basin, located in the northwestern part of Sonora. This research involves participatory modeling techniques designed to increase water manager awareness of hydrological models and their use as integrative tools for water resource management. This study was conducted as preliminary research for the participatory modeling grant in order to gather useful information on the population being studied.

This thesis presents research from thirty-four in-depth interviews with water managers, citizens, and agricultural producers in Sonora, Mexico. Data was collected on perceptions of water quantity and quality in the basin, thoughts on current water management practices, perceptions of climate change and its management, experience with, knowledge of, and trust in hydrological models as water management tools.

Results showed that the majority of interviewees thought there was not enough water to satisfy their daily needs. Most respondents also agreed that the water available was of good quality, but that current management of water resources was ineffective. Nearly all interviewees were aware of climate change and thought it to be anthropogenic. May reported experiencing higher temperatures, precipitation changes, and higher water scarcity and attributed those fluctuations to climate change. 65% of interviewees were at least somewhat familiar with hydrological models, though only 28% had ever used them or their output. Even with model usage results being low, 100% of respondents believed hydrological models to be very useful water management tools. Understanding how water, climate change, and hydrological models are perceived by this population of people is essential to improving their water management practices in the face of climate change.

Chapter 1: Introduction

In the face of climate change, arid regions are expected to experience more extreme precipitation variability (Browning-Aiken 2007). In the U.S. -Mexico border region, these projected changes, along with rapid expected population growth, will likely contribute to severe water shortages for households, agriculture, and ecological systems (Browning-Aiken 2007). Water quality is also an issue (Burmil et al. 1999). Water-related perceptions affect water management decisions. These decisions are particularly important in regions experiencing extreme quality water scarcity (Burmil et al. 1999).

The Sonora River basin in the northwestern state of Sonora, Mexico is dry with dominant shrubland vegetation and sandy soils (INEGI 2009). The basin consists of three distinct watersheds: upper, middle, and coastal. The upper basin is largest with most of the agricultural users, while the Sonoran capital Hermosillo, is in the middle basin. Hermosillo has about 700,000 residents and is growing at a rapid 1.5% per year (CONAPO 2008).

Hermosillo is withdrawing water from surrounding aquifers more quickly than it is being replaced (Moreno Vazquez 2006). This increases the likelihood of future severe shortages. The largest water demand in the basin comes from Hermosillo and agricultural users (Moreno Vazquez 2006).

Many agencies manage Sonoran water in the Hermosillo area. These include the national water commission: CONAGUA; the state water commission: CEA; the municipal government: Agua de Hermosillo, and watershed council groups (Aparicio

2010). The work that these groups do revolves directly around water resources. Additional ministries have lesser water-related responsibilities that are part of a larger set, including: SAGARPA: the agriculture ministry; CEDES: the commission for ecological health and sustainable development; and SEMARNAT: the environment and natural resources ministry; SEDESOL: the social development ministry; and CONANP: the commission for natural protected areas (Aparicio 2010). Finally, there are other, smaller, groups focused on local areas or professions for whom water is a much smaller part of their mission statement. Examples of these groups include: farmers and ranchers associations, committees, and private water consultants (Aparicio 2010). All of these groups together have goals to manage water in the Sonora River Basin, and attempt to influence water-related decisions.

Attempting to incorporate all their different viewpoints and goals into decision making is difficult. Some advocate an integrated approach facilitating sustainable water management through adaptive management and conflict resolution (Browning-Aiken et al. 2004, Syme et al. 1999, Falkenmark and Rockstrom 2006). Although integrated management would require communication between many parties, these discussions could be constructive (Browning-Aiken et al. 2004).

One such tool is participatory modeling (Atunes et al. 2006, Cabrera et al. 2008). Participatory modeling is a collaborative technique using a participatory approach to data collection in order to better understand the opinions and concerns of affected parties (Cabrera et al. 2008). Participants share perceptions and concerns used to create some form of model. Because it is broadly grounded, the model can assist in developing better

management decisions (Cabrera et al. 2008). Participatory modeling can facilitate the integration of public values with technical information (Atunes et al. 2006).

My thesis reports on results from interviews preliminary to a future participatory modeling efforts in the Sonora basin. Interviewees were community members and agency officials in Hermosillo and the Upper Sonora River Basin. I questioned them about their perceptions of regional water quantity and quality as well as their perceptions of the use of watershed models as management tools. My results might be used to develop pre- and post-survey questions for 2013 regional participatory hydrological modeling workshops.

Chapter 2: Background Information

Climate change and water resources

Climate changes have global impacts including on water resources especially in arid regions like the study area, Sonora (Covich 2009). Freshwater availability is very sensitive to climate because hydrological processes, including evaporation and precipitation, are highly sensitive to temperature (Carpenter et al. 1992, Covich 2009). Compounding regional impacts is the fact that residential water demands are generally higher in arid regions and aquifer extraction in coastal Sonora is allowing seawater intrusion worsening water scarcity. (Schleich and Hillenbrand 2007, Yurdusev and Kumanhoglu 2008). Water scarcity can cause problems ranging from unemployment to famine, and even landscape issues such as erosion, soil infertility, and vegetation loss (Covich 2009, Schroeter et al. 2005). Because regional water reductions will have such diverse impacts, improved water management in the face of climate change is essential.

In addition to climate change, population levels are also rising rapidly in many arid regions around the globe (Vorosmarty et al. 2000). Associated urbanization trends concentrates water demand (Vorosmarty et al. 2000). Climate change will greatly affect arid regions such as Sonora, Mexico (Magana and Conde 2000). Significant changes in precipitation patterns are expected, along with decreased water availability, and higher water demand exacerbated by population increases (Covich 2009, Limberg et al. 2010, Loomis et al. 2000, Schroeter et al. 2005). This combination of factors puts residents of arid urban areas at particularly high risk of water scarcity, making it particularly

important to understand what effects water resource decision making in places like Sonora.

Sonoran water resources

Mexican water policies aim to sustain hydrologic systems, improve water quality and sanitation, increase potable and irrigation water availability, and protect against floods (Paredes 1997). (Sweetnam et al. 1999), Waterborne disease is a major problem that could be exacerbated by climate change (Deborah 1999, Paredes 1997). Increasing water use efficiency is a priority, especially in Sonoran irrigated agriculture. The Mexican government plans to achieve these goals through: the clean up of polluted river basins, including the Sonora River; creating a new water culture where the public perceives water as more of a natural resource than a right; maximizing private sector profits; and strengthening relationships between state and municipal governments (Paredes 1997). Fulfillment of these goals is possible, although challenging due to financial instability, governance issues, and global climate change.

Hydrological models

Models are also useful for exploring and defining conceptual framework of natural and managed water resources systems. Hydrologic models are conceptual, and often simplified, representations of the water cycle in an area under certain conditions (Kepner and Semmens 2004). Hydrologic models can assist water management decision

making because of the predictive output scenarios they provide. Many models are used to predict the impacts of certain water conservation policies (Kepner and Semmens 2004). Martinez-Fernandez et al.'s (2000) dynamic systems model integrated socioeconomic and environmental variables. It predicted the effects of proposed water conservation policies, allowing decision makers to understand that these policies would be insufficient without additional household conservation (Martinez-Fernandez 2000).

Of the government agencies partaking in water management in Sonora mentioned in the introduction, CONAGUA, and CEA occasionally use hydrologic models to manage certain watersheds, but could use them more frequently (Sandoval 2004). As will be discussed in the results of this study later on, very few other water management groups in Sonora use hydrologic models as management tools on a regular basis.

Hydrological models are important tools used in the solving of a variety of water resource management issues (Kepner and Semmens 2004). Because of the versatility of their functions, there are many different kinds of models. Some models may be created solely by hydrologists where all data input is scientific (Martinez-Fernandez 2000). Other models can be used to value ecosystem services (Guo and Li 2000, Kosoy et al. 2007, Wilson and Carpenter 1999). And still other models can be used as a way to interface with the public or government officials to get their input and allow for cross-communication and the integration of diverse data sources (Brown 2004, Castella et al. 2005). These models where outside input is gathered and used in the modeling process is referred to as participatory modeling.

Participatory modeling

Participatory modeling brings diverse participants together with modelers to provide input into a decision, model, or policy discussion. Participatory modeling first began in the 1960s with forest system dynamics modelers allowing client input (Voinov 2010). The process developed from there, and became what it is today by the 1990s (Voinov 2010). It is a coordination of effort that has become increasingly popular today (D'Aquino et al. 2002, Gaddis et al. 2010, Jones et al. 2009). Participatory modeling, as a technique, is most often used in regulatory decision making for fields where models are commonly used. These most commonly include socioeconomic scenarios and natural resource management (Voinov 2010). Because models are predictions of future scenarios, they can contain high error levels (Leavesley 1994). Uncertainties can be reduced through incorporation of reliable data, and developing a thorough model based in accurate assumptions of ecohydrological dynamics (Leavesly 1994).

Though commonly referred to as a single management or research strategy, participatory modeling efforts have diverse characteristics. Sometimes participation is limited to managers or government officials (Atunes et al. 2006, Jones et al. 2009, Yearley et al. 2003). Sometimes they include the public (Cabrera et al. 2008, D'Aquinto et al. 2002, Korfmacher 2001). Participants may come from the same professions (Cabrera et al. 2008), or they can be diverse depending upon conveyor's goals (Voinov and Gaddis 2008). It is this variability, along with the fact that participatory modeling can be used to integrate hydrological and socioeconomic data with climate change

scenarios, that make it a potentially valuable tool for use in the Sonoran Basin (Magana and Conde 2000).

Chapter 3: Literature Review

Perceptions and water resources

Water-related perceptions are important because they can affect their water-related behavior (Clay et al. 2007). However, the effects are not always as expected (Mills and Schleich 2009). One Pacific Northwest study showed that, respondents admitted participating in activities harmful to water quality even though they believed people should protect water resources (Clay et al. 2007). These discrepancies between perceptions and behavior likely occurred because the individuals did not realize that their behaviors negatively impacting water resources (Clay et al. 2007). Environmentally protective behaviors can increase when people understand the relationship between their behaviors and environmental impacts (Glig and Barr 2006).

Although the public usually overestimates water-related problems, sometimes they fail to realize the severity of problems (Crampton and Ragusa 2008). An Australian survey found that men and women underestimated local water shortages (Crampton and Ragusa 2008). Most respondents believed sufficient local water was currently available and did not expect the situation to change, although the area was experiencing water shortages expected to worsen with time due, in part, to climate change (Crampton and Ragusa 2008).

Personal characteristics can also play a role. People with more education and volunteer experience were more likely to conserve water (Glig and Barr 2006, Van

Wilgren et al. 1998). Norms can also be important. Those who always turned off the faucet while brushing their teeth were more likely to continue than those who had recently decided to conserve (Glig and Barr 2006).

However, those patterns don't always hold (Schleich and Mills 2008). One study found that Australians with strong environmental values wanted to conserve water, but believed that there were too many obstacles to conservation including increased expense and inconvenience (Hurlimann and Dolincar 2010). The gap between beliefs and behavior is a common theme in the water perception literature. Many researchers have therefore attempted to understand the connections between intentions, moral obligations, perceived rights and actual behavior.

One researcher found that those with current and prior intentions to conserve water were more likely to actually conserve water, while those who only claimed to have moral obligations to do so were not (Lam 1999). In addition, individuals who believed they had a right to water were more likely to behave in ways that negatively impacted water resources (Lam 1999). People who value water resources aesthetically are also more likely to conserve it (Kaltenborn and Bjerke 2002).

Information can influence action. People who knew more about water protection policies and science were more likely to be environmentally-oriented and exhibit water conservation behaviors (Steel et al. 1990). Perceptions of the ease of an action can also affect water-related behavior. One study found that most respondents believed water conservation to be too difficult to carry out (Randolph and Troy in 2008). The belief that

water-related behavior was overly regulated also decreased conservation-oriented behavior (Randolph and Troy 2008).

A final important factor in the links between water-related perceptions and behaviors, focuses on differences between the public and officials. Pierce and Lovrich (1980) found that the public was split between people who were highly and not at all concerned about water resource protection. They also found that local officials' water-related concerns were strongly associated with their generally accepted party affiliations where left wing representatives more likely to conserve (Pierce and Lovrich 1980).

McDaniels et al. (1997), investigated differences between public and water managers' perceptions of water-related risks. For most types of risks, they found much greater variation in the level of public versus managers' concerns. They also found that the public tended not to believe that policies could help solve water-related problems. The researchers suggested that because the public believed environmental problems can't be solved, they tended to become apathetic about water conservation behaviors (McDaniels et al. 1997). They argued that increased water-related outreach campaigns communicating successes in solving problems could increase public support for water protection policies and behaviors (McDaniels et al. 1997).

Climate change and water management through models

Subak (2000) studied water managers' climate change-related perceptions. They found that many managers reported changes in summer precipitation patterns, with

decreased rainfall, coming in fewer, more intense storm events (Subak 2000). Respondents also reported hotter summers and reduced water availability. Many believed it necessary to change water management decisions to respond effectively to current changes and better prepare for those in the future (Subak 2000).

Attempting to manage water resources in arid areas under climate change is a challenge in part because future levels of change are difficult to predict. Hydrologic models that incorporate climate change can help. These models integrate current water cycle and climate data with possible future scenarios changing precipitation (Leavesley 1994). Many types of models exist. Some are conceptual, some predictive, while others are quite complex, and many are based on different assumptions (Leavesley 1994).

During different participatory modeling scenarios, participants take on different roles. Sometimes they help create the model. Cabrera et al (1992) enlisted the help of Floridian farmers in the creation of the Dynamic North Florida Dairy Farm (DyNoFlo) model. The overall goal of the participatory modeling workshop was to reduce agricultural nitrogen emissions (Cabrera et al. 1992). Farmer participation was therefore essential. However, the researchers never formally evaluated impacts from participation in the workshop (Cabrera et al. 1992).

Other participatory modeling strategies ask participants to help improve an existing model (D'Aquino et al. 2002). For example, D'Aquino et al. (2002) asked participants to 'play' with their models as if they were games. They were then asked to evaluate each experiment or game and suggest improvements (D'Aquino et al. 2002). Castella et al. (2005) asked Vietnamese community members for improvements to their

geographic models. Yearley et al. (2003) used British community members to improve their models of air quality problems. They found that even these non-experts provided valuable information that greatly improved their models. Although frequently undervalued, community input often has great potential to improve models and have a positive impact on participants (Bhattacharyya et al. 1994, Pahl-Worstl et al. 2007, Pahl-Worstl et al. 2008).

Participatory geographic information systems (PPGIS) is an increasingly common technique. PPGIS users map an area or phenomenon using computerized geographic information system (GIS) (Sawicki and Peterman 2002, Sieber 2006). It is often used in natural resource management (Halvorsen 2006). PPGIS can create aesthetically pleasing and clear model displays that help put participants at ease and make the models easily understandable (Sieber 2006).

A final participatory modeling technique involves participants in using a completed model, usually to teach them how to use it. For instance, one such workshop provided lessons on model use combined with data collection on participant perceptions of potential projects (Rambaldi and Callosa-Tarr 2001). This is the type of modeling exercise we will use in the project for which my reported work is the first step. Sonoran decision makers will learn how to use our hydrological model and view the outcomes of different water management strategies under a set of climate change scenarios. Pre and post-surveys will measure participant perceptions of the model, workshop, and water resource needs.

Prior research has shown that participants highly value participatory processes designed to be inclusive, comfortable, and accessible (Halvorsen 2001). Such participation can significantly improve their perceptions of organizing officials (Halvorsen 2003). Participatory modeling can be a valuable tool in decision making within complex, conflicted situations (van Eeten et al. 2002). However, few participatory modeling exercises have been systematically assessed with high quality, quantitative pre- and post-meeting instruments. My preliminary interviews will be useful in developing those surveys and designing more useful workshops for 2013.

The majority of participatory modeling studies have claimed success for their project without ever assessing that success systematically (Cabrera et al. 2008, Van Eeten et al. 2002). When success is claimed without any formal evaluation, these assumptions undermine the process of participatory modeling (Parkinson 2009). Often, the assumption arises from a disparity between researchers and participants in terms of norms and perceptions (Parkinson 2009). Systematic assessment of success, either for the model or for the participatory process as a whole, can be done through a variety of different assessment tools (Holte-McKenzie et al. 2006).

One possible pathway is to have a set of questions aimed at allowing the participants to evaluate the participatory process that all involved are required to answer (Scarinci et al. 2009). Another option is to employ an evaluator to participate in the modeling process and observe those involved. This would include commenting on behavior, demeanor, and their level of participation in the process (Scarinci et al. 2009). This evaluator would remain constant throughout to process and therefore provide

constant evaluation data on participants in the process (Scarinci et al. 2009). Theories can also be used to evaluate participatory modeling projects (Hermans et al. 2012). In this case, common assumptions and difficulties of the process are identified and possible solutions are developed (Hermans et al. 2012). Finally, there are models that have been created to evaluate participatory modeling projects where data similar to that collected by an evaluator on participant behavior and participation levels is used as input (Scarinci et al. 2009).

Even with all these different strategies to systematically evaluate the success of a participatory modeling project, very few researchers have attempted to use them in practice. One example of a study that did undertake this task is that by Parkinson in 2009. She conducted a participatory modeling project in Uganda examining community input on a rural development project. Participants in this study reported, in exit interviews, that they agreed to participate because they believed it would help to improve their community. But they also stated a dislike for the technical requirements of the officials (Parkinson 2009). This caused a power dynamic between the researchers and the participants that led to a less successful participatory modeling project, as perceived by the participants.

Another example of a study were systematic data was gathered on the success of a participatory modeling project can be found in the work by Hermans et al. in 2012. The authors in this study conducted a participatory exercise for the modeling of a watershed management plan where their participant population was the local water board. In this case, the monitoring of the effectiveness of the project came in the form of

follow up evaluations on the model and water management after the project had been completed (Hermans et al. 2012). In this study, the seven-year (2009-2015) monitoring efforts were deemed necessary in order to determine if the participatory modeling project had been successful or if adjustments needed to be made. Several adjustments were made, and monitoring continues today (Hermans et al. 2012).

A participatory modeling project can be evaluated and improved through both monitoring practices and participant assistance. In a study by Holte-McKenzie et al. in 2006, researchers examined the efforts of a Kenyan NGO through models. In this process, members of the NGO were interviewed in order to determine the best direction for the model. The model was then created and presented to the participants. NGO members provided feedback on the model and the process multiple times and changes were made accordingly (Holte-McKenzie et al. 2006). This form of evaluation of a participatory modeling technique proved successful, because the NGO member participants were satisfied with the model after all their opinions were taken into account (Holte-McKenzie et al. 2006).

Systematic evaluation of the participatory modeling project is a very important step for researchers who wish to claim that their study was a success. Currently, this step is underused, but it is becoming more important. Some researchers chose to use individuals who have either participated in a participatory modeling process before, or who have conducted one, as participants in their own studies (Nichols 2002). This allows for a participant population that is more experienced with the project and more likely to exhibit positive behaviors, give good input, and provide a beneficial for evaluation if one

is conducted (Nichols 2002). Overall, gaining insight into the success of a participatory modeling project through participant surveys or interviews, monitoring strategies, or behavioral evaluation models is an uncommon, yet important step in all such studies.

In terms of this project, the fact that preliminary data has been collected on the target population for future participatory modeling workshops, water managers in the Sonora River Basin, creates a high likelihood that the project would be evaluated as a success. When participants feel valued, helpful, and as though the project will be beneficial for them and their community, they are more likely to report the project was a success (Parkinson 2009). In addition to the preliminary data, the larger project will also collect pre- and post-workshop surveys gathering input from participants. With the workshops being tailored to the responses from the preliminary interviews, it is likely that participants will feel valued, and evaluations will be positive.

Even if that is not the case, the fact that preliminary data and pre- and post-meeting surveys were collected, this study will fill a gap in the participatory modeling literature simply because not many researchers gather data from their participants in an attempt to evaluate their study. The responses to the preliminary interviews can help to understand how participants define water problems in their area. That information could help to develop the workshops and to better understand how to address those issues in the hydrological models being presented.

Chapter 4: Research Design

My goal was to gather answers to key questions from potential participants in this participatory modeling workshop. There were three major topics pertinent to the workshop. The first involved understanding how these potential participants viewed regional water quality and quantity, current water management, and water usage. I also wanted to know what they knew about and how they perceived hydrological models. Finally, I wanted to understand their climate change-related perceptions. My question protocol is in Appendix B in Spanish and English.

All interviews were conducted in Spanish and the results presented in this paper have been translated. A translated version of the interview questions asked can be seen in Appendix C along with the original Spanish version.

A slightly altered set of questions was asked of water users, including community members and agricultural workers. In that version of the questions, less was asked about the individual's experience working with hydrological models, and more was asked about their opinions on how often, and to what extent, their community discusses water issues. Spanish and English versions of these water user questions are also included in Appendix C.

In order to solicit water agency staff to interview, I compiled a list of relevant Sonoran government water agencies. I obtained names and contact information for potential individual interviewees in those agencies through colleagues who had worked in Sonora in the past doing similar research. I solicited interviews with a formal

invitation letter. Copies of both the English and the Spanish invitation letters can be found in the Appendix A. Of the 30 individuals asked, 16 agreed to be interviewed. They provided names of additional potential interviewees yielding an additional five interviewees and five more were successfully solicited at the time of these in-person interviews, giving a total of 26 interviews with agency officials. More water managers were interviewed in this study as compared to users because they are target population for the 2013 workshops. Because of this, their thoughts on water resource issues were more relevant to the larger study.

In order to gain a broader sense of potential water problems and solutions, I interviewed eight water users who were farmers, ranchers, urbanites, and rural residents from Hermosillo and the small town of Ures in the upper basin. The four urban user interviewees volunteered to participate when they were approached in public areas around Hermosillo. These public areas included the mall, a small outdoor park, and the public library. The Ures interviewees were identified with regional agency staff assistance.

While in Sonora, I was assisted by a native Sonoran who has a PhD in hydrology from the United States. She shared driving, interviewing, and note-taking tasks, conducting all user interviews and taking notes during all water manager interviews. I conducted a total of 34 interviews whose composition is shown in Table 1. All interviews were conducted in Spanish in which I am fluent.

Table 4.1
Composition of interviewees

Type	Category	Number of Interviewees
Agency Officials	CONAGUA	4
	SEMARNAT	4
	Union of Settlers: Costa de Hermosillo	1
	CONANP	1
	Technical Watershed Committee	1
	Farmers Association	1
	SEDESOL	1
	Private Consultant	1
	CEA	1
	SAGARPA	2
	CEDES	3
	Ranchers Association	1
	Municipal Government: Agua de Hermosillo	1
	Institute for Integrated Watershed Management	1
	COTAS: Mesa de Seri	1
	Watershed Council	2
Users	Urban Citizen	4
	Rural Citizen	1
	Farmer	2
	Rancher	1
Total		**34**

Interview length varied from 10 to 150 minutes with an average of about 30 minutes. All participants answered the questions asked, no participant refused to answer on any grounds. Each interview was recorded with the permission of the interviewee, and each interview was transcribed verbatim.

The transcripts were then coded by question. Each interviewee's response to each question was labeled and sorted. For example, when the transcription from interview 25 read: "How long have you lived in Sonora?" that line would be labeled: I25Q1 and the corresponding response would be labeled: I25A1. This process allowed for more ease in the sorting process that came next. During the sorting process all interviewees' responses to a single question were sorted into a single document so that, for instance, all the answers to Question 1 were in one file, Question 2 in another etc. Each set of responses to each question was analyzed for content and patterns. The results are presented in the next section.

Chapter 5: Results

Occasionally an interviewee was not asked a question. Responses therefore sometimes add up to less than 34. In addition, the majority of interviewees had lived in Sonora their whole lives, and the average length of time of employment at the water management agencies was 10.7 years.

Perceptions of water

Water quantity

Participants were asked if they believed there was enough water to satisfy the people's needs. Just eight (24%) interviewees believed there was, while twenty-five (76%) said that there was insufficient water now or in the near future. Based on interviewee responses, they perceived the term 'daily needs' to mean domestic use, agricultural use, and personal consumption. In response to this question, a local government representative discussed the amount of water "in the houses and in the fields." The term 'enough water' was also left up to the interpretation of the interviewees. Based on responses, participants took this term in relation to basin residents' 'daily needs.' Therefore, a belief that there was enough water to satisfy daily needs signified that there was water available for cooking, cleaning, consumption, agricultural, and sometimes gardening uses.

When asked why they believed there was not enough available water, the most frequent causes offered for a lack of water were overuse (19 interviewees: 56%), a lack of awareness of the need for conservation (11 interviewees: 32%), rain patterns (seven interviewees: 21%), and population increases (five interviewees: 15%).

For instance, one interviewee said:

> *We've always has water shortage problems in Hermosillo. Because of all the different sectors that need it for domestic use: farmers, ranchers, etc. Hermosillo has also grown quite a bit because of new job openings. It is attracting more industrial workers and also people from other states. There is just not enough water for that many people. The wells are dry, and alternative sources like more wells and aquifers are overexploited. And the rains too. Every day less rain falls and the groundwater never gets replenished.* Interview 30 (Local government official)

Some respondents stated reasons why water quantities were low and how to handle the issues. When asked if people had enough water for daily needs, one national level official (Int 1) stated: "I think people need to learn to live with what they have." This example shows a water manager's belief that the public needs to change their views on water and adapt to circumstances. Other interviewees commented that community use of water and their perceptions of it as a resource contributed to its overuse.

> *The lack of water also has a lot to do with the fact that many people don't have the consciousness to conserve water. A lot of people live, or want to live, as if water were never-ending… The way the population uses water contributes to there not being enough*. Interview 6 (National level official)

This opinion was also echoed in sentiments from interviewees discussing how water misuse was common, how people needed to change their views on water, and how water was a necessity. An example of such opinions can be seen in the following quotes: "Yes, water scarcity is a problem for everyone, it affects everyone…all the farmers, if they don't have water, they can't plant." National level official (Int 21). Another interviewee stated:

> *Really the problem is that water is poorly distributed. There are people who have large volumes of water, and people who don't even have enough to drink. It's very unequal. There are also bad use practices. Bad irrigation in the agricultural sector, bad consumption in the urban sector. The people don't value water…* Interview 11 (State level official)

In addition to comments on public perceptions of water, some interviewees gave particularly thoughtful, detailed responses. For instance, one said:

> *The water in the wells is not enough, and the water from the Sonora River is not enough. We have to find alternative sources of water. Like from the Yaqui River. The Sonora River is only 150 cubic meters and the Yaqui River is 3100 cubic meters. The aquifer has a recharge of 250 cubic meters. This leaves us with two options [for water management], desalinization or bringing water from the Yaqui River. The farmers in the Yaqui River Valley are furious about this idea. But we don't sell water to the farmers.* Interview 2 (National level official)

Four interviewees (12%) provided the water use restrictions of the past as evidence that there was insufficient water. These past bans restricted when Hermosillo residents could use water. One interviewee stated:

> *No. Today there is not enough water. The idea behind the use restrictions was based in the fact that the aquifers were being overexploited…Now we don't have the use restrictions anymore, put that does not mean that we have fixed the problem.* Interview 8 (National level official)

A final point in the data used to analyze the question of perception of water quantity has to do with the user responses. The users responses were split with four (50%) saying that there was enough water and four (50%) for there was not.

Water quality

Interviewees were also asked if they thought their water was of good quality. Nineteen (56%) of respondents believed their water to be of good quality while eight (23%) said it was poor quality. Several went on to explain what made them classify the quality as poor. For example, one said:

> *Well the water can be considered contaminated because it contains salts. Because of the salts, it needs to be treated…to remove them. Or in the case of a house, a filter is needed*. Interview 3 (National level official)

Another explained:

> *Well there are reasons why I say no [that the water is not of good quality]. There are times when I turn on the faucet and the water comes out like sand. I think it's a problem with the pipes, that they need to be*

changed or something. But that water is not of good quality. Interview 28 (State level official)

These are common types of responses offered by the 19 interviewees who believed the area had poor water quality. The remaining eight who believed it was good quality simply stated the fact and offered no explanation as to why they believed that.

Water management

Twenty-two (65%) interviewees did not believe current Sonora River water management policies were effective. Twelve (35%) believed it was, or that it was improving under the new administration. Eight (24%) respondents simply stated no, management was not effective, and offered no further explanation, but many explained why. For example, one said:

No [water management is not effective]. There is a very bad water culture in the management of water. We don't take care of it. One reason for that is the bad education on the subject in schools. We aren't educated in the field of natural resources and their value, in the protection of water. And another reason is the lack of authority. There lacks order in the water service sector. A lot of the water supplied is not measured. When you

> *don't measure the water, you waste it because it doesn't cost you anything. There is a large lack of authority in measuring and charging for water measured.* Interview 2 (National level official)

There were seven (21%) respondents who suggested better outreach as a possible way to improve water management. An example can be seen in the following quote.

> *I think that we need to apply and establish much better water management here in Hermosillo. We are lacking. And we also need to change the attitude of people about water in the city. We need more education. That is the key to improving water management.* Interview 3 (National level official)

Others believed that the laws needed improvement before management could improve, for instance, one said: "…we don't have clear policies that would allow for efficient management of resources." National level official (Int 14).

Twelve interviewees (35%) also mentioned the issue of overuse in the agricultural fields in the Upper Sonora River Basin. In this area, farmers are not charged for the water they consume and what they take is not quantified. Because of this, the time of day that many farmers choose to irrigate leads to high amounts of water loss due

to evaporation. One interviewee's thoughts on managing this issue can be seen in the following quote:

> *Right now we are trying to get the farmers to control their irrigation systems better. Trying to control how much they use. In terms of water, we are trying to implement better irrigation systems that don't waste so much water. Using this new technology could greatly improve water usage in Ures, San Pedro, Santiago…it would help reduce waste from evaporation, making irrigation more efficient. That's what we are trying to do.* Interview 21 (National level official)

A final common reasoning for poor management was the poor water resource distribution which was mentioned by four (12%) interviewees. For example, one interviewee stated:

> *I believe that the past administrations have made an effort to improve water management in Hermosillo. But even still, there is still a lot to do in order to make sure that our concerns are addressed. The improvement of provisions requires management throughout the watershed to restore the hydrological regime and establish strategies to compensate for*

deficiencies in the distribution of the quantity and water quality. Interview 33 (Local level official)

When asked if they were concerned about water resource management, 29 (91%) of interviewees asked stated that they were. A local government official (Int 4) stated: "Of course [I'm concerned]. It's part of our job description. That the people work to maintain water quality and security into the future." Twenty interviewees (63%) reported issues of water quantity and quality when asked what concerned them, five (16%) did not elaborate, and the remaining four discussed issues of leaks in infrastructure, use restrictions, increasing efficiency of use, and government projects.

For example, interviewees stated: "I'm more concerned with making water use more efficient in Sonora than issues of quantity and quality." National level official (Int 20). And also: "Yes. It's very concerning, all the situations I've told you. Very concerning quantity and quality. For example, the Sonora SI project, that concerns me a lot." Local level official (Int 9). These outlying issues concerning respondents were in the minority, while most participants were much more concerned about water quantity issues.

Well, the water quality, I think it's acceptable. But the quantity, that does concern me. The combination of little water and the low consciousness of

the people is something to be concerned about. Interview 6 (National level official)

Water management perception data was also analyzed according to level of water management. Nine interviewees worked with water management most often. Seventeen worked with water management on a lesser level, and eight were user interviewees who worked with water management the least.

Of the nine interviewees that worked with water management most often, four (45%) stated that current water management was satisfactory or improving. The remaining five (55%) believed that it could improve. Of the 15 agency officials with less of a water management focus 3 (20%) believed water management to be satisfactory or improving, while 12 (80%) did not. And finally, of seven water users, three (43%) were satisfied with current management or believed it was improving, and four (57%) were not satisfied. Overall, 22 (65%) of interviewees believed Sonoran water management was unsatisfactory.

Hydrological models

Basic knowledge

The majority of participants were familiar with hydrological models (18 interviewees, 53%). Another four (12%) stated that they were somewhat and twelve (35%) were completely unfamiliar with hydrological models. Of the twelve interviewees who were not familiar with hydrological models, six of them were water users. when

models were explained to them during the interview, The remaining six (18%) participants, were familiar with the basic concept.

Based on these responses, the term ‘familiar’ seemed to signify to the interviewees a very small level of exposure. Respondents stated they were familiar with hydrological models while stating: “I have friends who talk about those.” National level official (Int 6) or: “in reality, they just pass me the information, and that’s how I know about them.” National level official (Int 1). There were also interviewees with a great deal of modeling experience who had knowledge of their uses and limitations who also reported being familiar with the models. “I am familiar with how the hydrological models work and what they are used for.” Local level official (Int 12). Overall, the term ‘familiar’, in this context had a wide range of meaning from passing information to years of experience.

Interviewees were asked to describe their experience with hydrological models. The following is an example of an interviewee response after an explanation on hydrological models had been provided:

> *Yes, I know what they are. But look, what I have are the results that those models produce. The models are run by my technicians. I’m not very familiar with them because I’m not a technician. But they do produce information that I use to help me make decisions. For example, models are frequently used in the agricultural cycles.* Interview 2 (National level representative)

This means that all water managers interviewed in this project were familiar, in some way, with hydrological models prior to the interview, and ten (29%) were more familiar with them after the completion of the interview.

In a breakdown of responses by agency, six (50%) of the interviewees who stated they were not familiar with hydrological models were users not involved in water management. It was also, often the case that representatives from the same agency responded with different answers due to their area of expertise being in different sectors of water management. When multiple representatives from a single agency were interviewed, they were from different sectors of that agency with different professional responsibilities.

In addition to participants responding with yes and no responses, another common answer to the question of familiarity with hydrological models was that the interviewee had some idea, but were not completely sure in their perception of the models. Four interviewees responded this way, and each respondent worked for a water agency. When these individuals were asked to summarize what they knew about hydrological models, they all gave accurate descriptions and, therefore, the interviewees with this response were simply being cautious, or they believed the models to be more complex. An example of such a response can be seen in the following quote:

> *Well, from what I understand models are used for planning and making rational water use more efficient. You enter data on how much water falls here, how much evaporates, and with that you can understand how much water it is feasible to remove from the system. And we can dictate this much for agricultural use and this much for human consumption.* Interview 15 (Local level official)

Other responses to the question on what a model is include:

> *Hydrological models are conceptual models describing input and output of water in a system. And the mathematical models that are managed for future simulation of volumes of water in aquifers and of would happen in a watershed. For both surface and ground water.* Interview 3 (National level official)

The previous quote is a good representation of what the interviewees believed a hydrological model to be. Some were more knowledgeable than others, but, when prompted, 15 interviewees (44%) gave accurate explanations similar to those above.

Data for this question was also analyzed based on the degree to which water management was central to their job description: this breakdown resulted in nine "water managers" for whom it was central, 17 officials for whom it was, at most, a minor part of their job, and 8 water users. This data shows that 6 (67%) of the water managers were familiar with hydrological models. Two (22%) in that same group were somewhat familiar, and the remaining 1 (11%) was not familiar. Of the other officials 10 (59%) were familiar, two (12%) were somewhat familiar, and five (29%) were unfamiliar with hydrological models. Two water users (25%) were familiar with the models, and the remaining six (75%) were not. For all interviewees where 53% were familiar with the models, 12% were somewhat familiar, and 35% were unfamiliar with them.

Model usage

Twenty (72%) interviewees had never used hydrological models in their professional work. Six (21%) had previously used hydrological models for water management and two (7%) had used output from hydrological models others had run for water management strategies. Therefore, even though all of the water managers interviewed had some level of familiarity with hydrological models, very few had ever used them or their output in any type of water management work.

Well I don't use them [models]. I know that they exists, I know that there are those out there that do use them for work and they fell that they are very important. They are very important. I think that, in Hermosillo, we need people that have the experience with these models because right now there are very few. Interview 5 (National government official)

Responses sorted by agency show that three of the four National level CONAGUA representatives use models or their output, along with several State CEDES ecological workers, the municipal government, and a representative for integrated watershed management. All other agency respondents did not personally use models in their daily work, though some representatives, such as the state water commission: CEA, did acknowledge that the models were used in their offices, just not by them personally.

Trust in models

100% of interviewees stated that they felt hydrological models were important tools, and most followed that up with enthusiasm and statements that translated into 'of course!' or 'obviously, yes'.

[Hydrological models] are indispensible. If we don't have or use those models, we are making blind decisions. That could lead to many severe

> *problems with the mismanagement of water. You have to plan ahead, and models allow you to do that.* Interview 2 (National government official)

This means that, even though the majority of the water managers do not use hydrological models or their output directly, they clearly feel that they are useful tools and would use them themselves under the right circumstances.

Even with such a consensus on the value of hydrological models, there were a couple instances where interviewees followed up their statements on the usefulness of models with warnings about using good data or being careful how the output was applied to management.

> *I think that hydrological models are good management tools, but they do have their limitations. The uncertainty associated with the inconsistency of historical records means you have to have a well-calibrated model that is reliable. That is the main constraint, but in the absence of updated information, and with the use of associated error margins, models are better than having no information.* Interview 33 (Local government official)

These few statements indicated that some participants were aware of the limitations in hydrological models. But even the individuals who believed that there should be stipulations in their use, thought that the models were very valuable tools for watershed management that should be used in the Sonora River Basin. All twenty-eight interviewees asked if they believed hydrological models were important sated that they were, and only four (14%) of those individuals also followed up their initial response with concerns about the models, their use, or their limitations.

Climate change

All of the 34 interviewees except one were familiar with the concept of climate change (97%). When asked what they thought was causing it, twenty-nine (85%) believed that climate change was anthropogenic, while the others felt unequipped to answer the question. For example, one interviewee stated:

> *It's a difficult concept. There are many changes happening today. Who is responsible? Man? Cosmic forces? It's not yet defined. It's very difficult. The users are aware of the changes, but how can we differentiate between climate change problems and naturally extraordinary events? Like the hurricanes, they have always hit us here, and now there are more. Is that climate change?* Interview 4 (Local government official)

Only 5 (15%) interviewees responded similarly to the above quote. Most stated believed climate change was causing: changes in precipitation patterns, both an increase and a decrease (27 interviewees: 82%); changes in temperature, increase and decrease (14 interviewees: 42%); increase of rare or extreme weather events such as hurricanes or even hail falling in July (6 interviewees: 18%); and drought (18 interviewees: 55%). This reported impacts of climate change were very closely tied to natural resource issues. For example:

> *Climate change refers to the effects of human behavior on the environment. Behavior like deforestation and air contamination. It's affecting the rains and therefore it affects us. Therefore we are all feeling the effects of the warming.* Interview 7 (National government official)

Based on responses, the majority of interviewees believe climate change is impacting water resources. For example, when asked to discuss what climate change meant to them, one interviewee stated: "…it's a question of climate. Here, it is principally rain." National level official (Int 21). Twenty-nine (88%) interviewees mentioned water resource changes due to climate change. Eighteen (55%) mentioned drought and 27 (82%) mentioned precipitation changes. Some interviewees mentioned both issues.

Because the majority of the interviewees were aware of climate change, believed it to be anthropogenic due to increases in carbon output, and claimed to have witnessed the effects on water resources already, there were many who wanted to see more government management of the issue. For instance, one said:

> *The government needs to implement programs that encourage the better use of water. Programs that will educate the people, including on the news and in the paper.* Interview 21 (State government official)

Nine (34%) respondents believed that Sonoran climate change management was either good or improving. And the remaining twenty-one (66%) were not satisfied with current climate change management by the government at any level. For example, one stated:

> *The state government, no [not managing satisfactorily]. The federal government does very little. Therefore, it's something that they should team up and do together. And the same for the people at the municipal government, Agua de Hermosillo. They are all implementing their own projects but to no avail…they are missing the implementation and follow-through of the people.* Interview 28 (State government official)

This suggestion for the different agencies to coordinate was also a common theme in responses to the question about what agency is most responsible for climate change management. In this case, only four (12%) individuals believed climate change management to be the responsibility of a single agency. Those agencies were: the National Water Commission (3 interviewees), and the Ministry for Ecological Health and Sustainable Development (1 interviewee). Thirty (88%) interviewees stated that it was the responsibility of everyone: Federal government, State government, Local government, and users to mitigate climate change. For example, one interviewee stated:

> *I think that we all need to be responsible. It's something that should be in all of our educations. There are agencies such as SEMARNAT that look at everything in general terms of what will affect the environment, and other agencies. But the contamination comes from all of us, the factories, the gasses, the vehicles. We all add something and it is therefore all of our responsibility. The government agencies, the citizens, everyone. There is a lack of consciousness in everyone.* Interview 2 (National government official)

Some of the final questions in the semi-structured interviews asked about perceptions of how water would be affected in Sonora by climate change. All eight users

commented on the changing rain patterns and higher evaporation due to heat. For example, one interviewee stated: “Well we’re already seeing higher temperatures over the past few years. And it’s also a lot drier than before. And less water primarily.” User (Int 18)

The water managers also discussed the precipitation and raising temperatures, but most went more in depth to comment on increased extreme events such as hurricanes and large flood storms. And some of the respondents went to even more detail because they had been examining the meteorological data for certain projects. One participant stated:

> *Two years ago was the driest year in history for Sonora… The waters have lowered up to 2 meters a year in some places. There is currently not enough groundwater to provide to the users in Hermosillo…. Tests have revealed arsenic, fluoride, and other chemicals. The waters have gotten hotter with rising temperatures, more polluted.* Interview 16 (State government official)

Data on who was thought to be responsible for management of water related changes due to climate change was analyzed based on the water management level groups of highest use of water management, lesser use of water management, and users. These results showed that eight (89%) of the higher-level water managers believed that

water related climate change management was the responsibility of multiple agencies and the public. The remaining 1 (11%) interviewee believed it was the responsibility of the National Water Commission.

The second group of water managers reported that 15 (94%) interviewees believed climate changed management in terms of water should be a coordinated effort between many agencies and the public while the remaining interviewee (6%) believed it was the responsibility of the Ministry for Ecological Health and Sustainable Development. Finally, results from the users group showed that five (71%) interviewees believed it was the responsibility of everyone to manage water and climate change, while two (29%) believed it was the responsibility of the National Water Commission.

The overall data showed that 88% of interviewees believed that a coordinated effort between many agencies and the public was needed in order to manage climate change effects on water resources. The group breakdown results report the same sentiment among the groups, but the users are more content with having the National Water Commission take charge than the two water managers groups.

With these detailed accounts of changes in water due to climate and other factors, as well as their opinions on how the issue should be managed, it becomes clear that many residents in the Sonora River Basin have noticed changes and are concerned about their water and it's management in the face of climate change.

Table 5.1 shows a breakdown of the majority response percentages for all the main questions described above. Based on these results, opinions concerning water

resources issues in the Sonora River Basin were found to be relatively similar between the respondents.

Table 5.1
Summary of majority percentage results

Category	Topic	Majority Percentage
Perceptions of Water Issues	Insufficient Water Quantity	76%
	Good Water Quality	56%
	Non-satisfactory Management	65%
Hydrological Models	Were Familiar	65%
	Never Used	72%
	Models Important Tools	100%
Climate Change Perceptions	Aware	97%
	Thought to be Anthropogenic	85%
	Non-satisfactory Management	66%

Chapter 6: Discussion

Because of current climate change issues, as well as issues of population growth and over consumption of water, the Sonora River Basin is encountering water management hurdles. Current water managers are addressing these issues in a variety of ways. These government workers are aware of the water issues mentioned above, as are the citizens in the Sonora River Basin. This awareness is encouraging because understanding that there is a problem that needs fixing is a good first step towards a solution.

The three main research questions in this study were:

1) What are the current perceptions of Sonoran citizens and water managers about their water quantity, quality, and management?
2) How do the current Sonora River Basin water managers and users view hydrological models? Are they aware of them? Do they use them? Do they trust the output?
3) What are the current perceptions of people in the Sonora River Basin on climate change? Do they feel that it will affect their water?

The overall results of the first question are: that the majority of the interviewees felt that there was not enough water to satisfy daily needs; that the water currently available is of good quality; and that current management of water in the Sonora River Basin is insufficient.

The results of the second question are: that the majority of water managers are aware of hydrological models and know how they work, while the majority of users do not; that most water managers have never used hydrological models or their output in their management activities; and that all of the respondents believe that hydrological models are useful tools for watershed management and that they should be used more often in Sonora.

And finally, the results of the third question showed that perceptions on climate change are relatively stable across the community. The majority of interviewees were aware of climate change, believed it to be anthropogenic, and thought that a water culture change was needed in order to begin to conserve and protect water in the area. When management was questioned, most of the participants did not find current actions in the face of climate change to be sufficient and they felt that collaboration and education initiatives would improve efforts. In terms of current effects of climate change, all respondents gave compelling arguments about changes in temperature, evaporation rates, weather events, and water levels over recent seasons.

Because many of the responses to the interview questions showed a majority viewpoint, they suggest a set of similar opinions concerning current water resources issues in Sonora. Because of this, using the data gathered in this study to help formulate models and strategies to address climate change in the Sonora River Basin should be an effective way to communicate with current water managers and users.

Many discussions can be raised, and many conclusions can be made using the results reported above. Overall each question above had a clear majority answer. This

could signify that any changes attempted in water management to address the problems mentioned above might be met in a positive manner. Water managers could accept the use of hydrological models or a more collaborative agency strategy to dealing with climate change. This may not be the case, but the overall agreement among respondents in this study could be found encouraging to future researchers and water managers.

The results of this study fell very well inline with current water perceptions literature. For example, environmentally-oriented behaviors and thoughts are more likely to be found in people with a larger environmental education background as well as whose understanding of the connection between their own behaviors and environmental effects is strong (Glig and Barr 2006, Steel et al. 1990). My results show this to be true of the water managers interviewed. They exhibit higher levels of natural resource education as well as a higher understanding of the connection between action and consequence in terms of water. These same interviewees were also found to exhibit high levels of environmental concern and comment frequently on how their constituents need to change their water damaging behaviors.

Another example of how this study follows water perception research can be seen in the responses of the eight users interviewed. Crampton and Ragusa (2008) found that the public underestimated the severity of their water quantity problem. This same situation occurred during this study's interviews. Four of the eight users interviewed did not believe that there was a water shortage in their area, while 81% of water managers stated that there was. In a different study, authors found that users were less likely to conserve water because they believed it too inconvenient (Hurlimann and Dolincar

2010). In this study, several of the agricultural users, as well as representatives from the local agencies that represented them, commented that they were unlikely to change their behavior because it was too much of a hassle.

One possible solution to agricultural water problems is reducing high evaporation levels associated with irrigation (Fernandez and Selma 2004), but the interviewees who discussed this type of problem stated that these producers don't want to change because they don't feel that they have to. A similar result was found in a study by Lam in 1999. He found that people who thought they had a right to water were more likely to misuse it and very unlikely to conserve it.

A final similarity between my results and those found in water perception literature is that where education is recommended as a solution to conservation problems. McDaniels et al. 1997 argued that increased water resource education and outreach campaigns to the public would yield a success in increasing support for water protection policies and conservation behaviors. This same sentiment was echoed by many interviewees throughout my research. Better education was recommended for both water conservation and climate change awareness. This advocacy for educational improvement was voiced by both water managers and members of the local public.

This research also reflected findings similar to climate change perception research. Subak (2000) studied the perceptions of water managers regarding climate change. He found that most managers stated that there were definite changes in summer precipitation patters such as decrease rainfall, and higher occurrence of stronger storms. These managers also stated that the temperatures in the summer had increased and

overall water availability was down (Subak 2000). These findings are almost identical to the results reported by the water managers interviewed in this study. Agency representatives reported experiencing higher temperatures, changes in rainfall patterns, and less water overall in the system.

The niche where this study contributes to current literature is in the field of participatory modeling research. This study was conducted because it is very rare for researchers to gather data on or from the subjects of their participatory modeling endeavor before or after the project itself. The participants in the 2013 workshops will come from the same population of water managers interviewed in this study. The information gathered in these 34 interviews on problem definition, concern levels, and areas where improvement is needed, will help to shape the language used in surveys to be given out during the workshop as well as to simply provide a better insight into how this group of individuals views their water resources. Because such a strong majority opinion was found between many different water management group members, if the workshops use the knowledge of that opinion on water quantity, climate change, and hydrological models, they could forge a good relationship with the workshop participants and perhaps get stronger results.

Because the primary goals of the workshops will be to encourage the use of predictive hydrological models in current watershed management in the Sonora River Basin, the responses to that particular set of questions is the most relevant. Those results show that most managers are aware of hydrological models and their uses, though they do not use them personally. Even though model use level is low, all of the managers

interviewed had high trust levels towards hydrological models that were created properly. The fact that these models were found by the participants of this study to be extremely useful integrative watershed management tools means that this same group of people are more likely to accept the models being presented at the workshops in 2013.

In addition to the contribution this study could make in the larger Sonoran water resources participatory modeling project, the results found in these interviews could also have implications proving the importance of gathering preliminary data for all participatory modeling studies. As mentioned above, the collection of preliminary data through these interviews allowed me to understand how Sonoran water managers define their water resource problems. For example, understanding the strong level of concern many interviewees had for unregulated water use in the northern, agricultural basin allows future researchers to understand that this issue should be addressed in future models.

Also, understanding the strong connection in the minds of the interviewees between climate change and water resources. When asked about climate change effects on Sonora, the strong majority of interviewees mentioned water in some form. This allows researchers to understand that their target population believes the concept of climate change management is directly tied to water resource management. This knowledge, as well as the information on a strong positive response towards hydrological models from the interviewees can help researchers address both climate change and water management in a coordinated way through hydrological models.

These same types of knowledge can be gained in other forms of participatory modeling projects. When researchers gather preliminary data they gain insight into how their target population defines problems and concepts. This information is very important because of possible cultural differences between the participants and the researchers. If different words or phrases are interpreted differently between the two groups, communication could suffer. The preliminary data allows the researchers to better understand the thought processes of their target population in terms of the issue being addressed. This knowledge can allow for better model formulation, better overall communication, and a participant population that understands the researchers are very concerned with understanding their viewpoints on an issue.

Satisfied participants who feel important in the participatory process are more likely to provide better evaluations of the overall project (Parkinson 2009). Positively evaluated participatory modeling projects are rare in current literature. If the process of gathering preliminary data on a target population can allow for a better understanding of their definitions of issues, concepts, and problems, it is possible that participants will feel more valued. These positive experiences could then translate into positive evaluations of the participatory process as a whole. So few current studies gather information from participants before or after the participatory session, and the same is true for studies that evaluate their processes systematically. This thesis can help to fill both gaps through systematically gathering preliminary data that can be used to better identify with how a select population is feeling and, by doing so, making them feel more positively about the experience as a whole.

In addition to being a contribution to current literature, this study also has possible future policy implications. Because all interviewed water managers believe that hydrological models are important management tools, and because this data may be used in several workshops where models are presented to managers, there is a possibility that this study could help to increase the use of hydrological models in Sonoran water management. With the possible increased usage of hydrological models, management practices involving water resources could change. The increased knowledge on how water will react to different environmental shifts in the area will allow for more directed and accurate management in the Sonora River Basin. This could, in turn, cause a need for change in future water management policy requiring the use of hydrological models or simply changing certain water use practices to conserve or upgrade to more efficient equipment.

Chapter 7: Conclusion

Major findings in this research concern perceptions on water quantity and quality in the Sonora River Basin, as well as perceptions on the management of that water. Perceptions on climate change and its management are also important. And finally, perceptions of participants on hydrological models and their value in water management were examined.

Water perception results show that for every major question mentioned above, there was a majority consensus amongst the thirty-four interviewees. Concerning water quantity, the majority of participants reported that there was not enough water to satisfy daily needs. Another majority stated that the water available to the residents of the basin was of good quality. And finally, most respondents reported that the current water management was insufficient and needed improvement.

In terms of climate change, the majority of respondents stated they were aware of its existence and believed it to be an anthropogenic effect. Most interviewees also reported having experienced changes in temperature, precipitation patterns, and water availability due to climate change. Finally, most of the respondents also stated that they thought management of climate change and its effects needed improvement, but that it was the responsibility of everyone in the area to help reduce the effects.

Answers to the hydrological modeling questions showed that most of the water managers were familiar with hydrological models and their purpose, but that very few had ever used one or its output in management work themselves. Though these models

were rarely used by the interviewees, all respondents stated that the models were very useful management tools and should be implemented more frequently in water management in the Sonora River Basin.

My results show a fundamental agreement between respondents about many water aspects such as quantity, quality, management, climate change, and even the validity of hydrological models. This indicates a good starting point for further study or work in the area of water management in the Sonora River Basin. The fact that the majority of participants from many different government agencies and water management groups have similar perceptions on a variety of different water issues means that collaboration or cross-communication on these issues is likely to go smoothly if ever attempted.

There were some limitations and biases found in this study. Firstly, the people who agreed to participate in the interview process were more interested in the subject of the research than the average Sonoran water manager, and some had been involved in similar projects with other Michigan Technological University students in the past. Also, for many agencies only a single interviewee agreed to participate. This did not allow for good response comparison between agencies, nor for making assumptions about the sentiments of a single agency. In addition to that, there was an imbalance between water managers interviewed and users interviewed. With only eight out of thirty-four interviewees being non-managers, it is difficult to compare responses between groups.

Avenues of future research include a series of participatory modeling workshops like those planned for 2013. These workshops will help to increase water manager's exposure to hydrological models and hopefully increase use of the models in daily water management projects. During those workshops, data will be gathered similar to the data gathered in this study. This data will help to increase knowledge on water, climate change, and hydrological modeling perceptions held by Sonorans and water managers.

With all the additional information gathered in the planned workshops, further future research could include a follow-up study examining if and how hydrological models are now being used in water management in the Sonora River Bain. This study could return and interview people from the same study population and ask questions similar to those asked in this and the participatory modeling study. The results could then be compared to this study and the workshop results in order to determine if there had been any change in water management. The timeline of this study could be anywhere from five to ten to twenty years after the completion of the participatory workshops.

Another possible avenue of research to build upon this study would be to follow the integration of hydrological modeling into a specific water management agency that had never previously used it before. Observations could be made on how well the integration goes, how much resistance there is to change and to the models themselves, as well as any change in the perceptions of constituents on the success of water management by that particular agency.

A final research possibility would be to examine current water management policy in the Sonora River Basin. A researcher could study the inclusion of models as management tools, as well as try and understand the policy behind some individuals being charged for water and others not. This study could attempt to improve water management policy in the basin by advocating for required efficiency upgrades for water conservation such as new irrigation systems that reduce evaporation. This study could use my results to find issues to examine and build upon.

Water management in the face of climate change is an important issue. With raising populations and temperatures in Sonora, Mexico, water issues have become increasingly relevant. It is necessary for water managers in the area to look to the future in order to understand the changing climate's effect on water resources. A very useful way to accomplish that is through hydrological modeling. If the presence of hydrological modeling in daily water management strategies increased, it is possible that water managers would have a better idea of what types of future scenarios are possible for water in the Sonora River Basin.

Along with the increase in hydrological model usage in water management, it is also important to understand current water perceptions in Sonora. Many mangers stated in their interview that the culture of water in Mexico needed to change. It is very important to value water as a resource necessary for life. Increasing education and instilling a sense of value for water at a young age could greatly increase the amount of water conservation occurring in Hermosillo, Sonora as well as the surrounding smaller towns. If people in the Sonora Basin were taught to value water and to conserve it, both

for intrinsic reasons and also because of its increasing scarcity, then it is possible that Sonora could get ahead of its water problem and help reduce scarcity.

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Appendix A: Interview request email

English:

Dear,

My name is Ellen Brenna and I'm a graduate student at Michigan Technological University. I'm studying water infrastructure in the Sonora River Basin by speaking with water managers and users in Sonora. I was wondering if you would be willing to speak with me briefly about this topic. I believe that your insight would greatly help my research.

I understand that you are very busy, and I would really appreciate any time you could give me. I have a series of questions asking for your opinions on water in Sonora. None of these questions are personal or sensitive, and any data I collect with be for research purposes only. Your name will never be associated with any of your responses. The questionnaire should only take 10-20min.

If you and/or some of your colleagues would be willing to speak with me, I would really appreciate it. I will be in Sonora from Aug. 7-18 and would love to speak with you.

Thank you so much for your time,

Ellen Brenna

Interview request email (Spanish female):

Estimado Sra. XXX (IF APPLICABLE, INCLUDE Dra. or Ing.)

Mi nombre es Ellen Brenna y actualmente me encuentro estudiando la Maestría en la Universidad Technológica de Michigan (Michigan Technological University). Como parte de mi tesis estoy estudiando la administración del agua en la Cuenca del Río Sonora, y con ayuda de la Dra. Andrea Muñoz-Hernández me encuentro entrevistando tanto a personas como usted que toman decisiones importantes en el manejo integral de la cuenca, como a los usuarios del agua en Sonora.

He elaborado un cuestionario relacionado a mi proyecto y su opinión profesional acerca del agua en Sonora es muy relevante e importante, y me será de gran ayuda en mi trabajo. Comprendo que usted ha de estar sumamente ocupada, pero realmente apreciaría que me otorgara unos cuantos minutos. Ninguna de estas preguntas son personales y cualquier información que se me proporcione será únicamente utilizada dentro de un contexto científico. Este cuestionario no tomará mas de 20 minutos y ninguna de sus respuestas serán asociadas con su nombre.

Si usted está dispuesta a responder las preguntas de este cuestionario, cuando puedo pasar a visitarla? Actualmente me encuentro en Houghton, Michigan pero tengo planeado estar en Hermosillo, Sonora del 7 de Agosto al 17 de Agosto. Si usted por

alguna circunstancia no puede, me podría recomendar a otra persona dentro de su institución que podría estar interesada en ayudarme?

Muchas gracias por su atención.

Ellen Brenna

Interview request email (Spanish male):

Estimado Sr. XXX (PLEASE INCLUDE Dr. or Ing. IF APPLICABLE)

Mi nombre es Ellen Brenna y actualmente me encuentro estudiando la Maestría en la Universidad Technológica de Michigan (Michigan Technological University). Como parte de mi tesis estoy estudiando la administración del agua en la Cuenca del Río Sonora, y con ayuda de la Dra. Andrea Muñoz-Hernández me encuentro entrevistando tanto a personas como usted que toman decisiones importantes en el manejo integral de la cuenca, como a los usuarios del agua en Sonora.

He elaborado un cuestionario relacionado a mi proyecto y su opinión profesional acerca del agua en Sonora es muy relevante e importante, y me será de gran ayuda en mi trabajo. Comprendo que usted ha de estar sumamente ocupado, pero realmente apreciaría que me otorgara unos cuantos minutos. Ninguna de estas preguntas son personales y cualquier información que se me proporcione será únicamente utilizada dentro de un contexto científico. Este cuestionario no tomará mas de 20 minutos y ninguna de sus respuestas serán asociadas con su nombre.

Si usted está dispuesto a responder las preguntas de este cuestionario, cuando puedo pasar a visitarlo? Actualmente me encuentro en Houghton, Michigan pero tengo planeado estar en Hermosillo, Sonora del 7 de Agosto al 17 de Agosto. Si usted por

alguna circunstancia no puede, me podría recomendar a otra persona dentro de su institución que podría estar interesada en ayudarme?

Muchas gracias por su atención.

Ellen Brenna

Appendix B: Interview question protocol

Office of Research Integrity and Compliance IRB #: M0528

Confidentiality Statement (English):

We're researchers from Michigan Technological University in US. We're talking with different water users and managers in the Sonora River Basin about some of the issues relating to water management. The questions should take 20-30 minutes, and primarily concern your own personal opinions. Your answers will help us understand your viewpoint on the issues we're studying.

Although we won't be asking sensitive questions, all of your answers will be confidential. Your name will never be associated with anything that you tell us. Although I'll be taking notes as we talk, it helps us to have a complete record of what you say. I can achieve that by recording our conversation. Are you comfortable with this?

The professors we are working with are Dr. Kathy Halvorsen and Dr. Alex Mayer. You can contact either of them or myself if you have any questions after the interview. We appreciate your willingness to participate in our research. Thank you very much for your time.

Confidentiality Statement (Spanish):

Mi nombre es Ellen Brenna y actualmente me encuentro estudiando la Maestría en la Universidad Tecnológica de Michigan (Michigan Technological University). Como parte de mi tesis estoy estudiando la administración del agua en la Cuenca del Río Sonora, y con ayuda de la Dra. Andrea Muñoz-Hernández me encuentro entrevistando tanto a personas como usted que toman decisiones importantes en el manejo integral de la cuenca, como a los usuarios del agua en Sonora.

He elaborado un cuestionario relacionado a mi proyecto y su opinión profesional acerca del agua en Sonora es muy relevante e importante, y me será de gran ayuda en mi trabajo. Comprendo que usted ha de estar sumamente ocupado, pero realmente apreciaría que me otorgara unos cuantos minutos. Ninguna de estas preguntas son personales y cualquier información que se me proporcione será únicamente utilizada dentro de un contexto científico. Este cuestionario no tomará mas de 20 minutos y ninguna de sus respuestas serán asociadas con su nombre. Le molestaría si grabamos esta entrevista?

Las personas encargados del proyecto en la Universidad Tecnológica de Michigan son los profesores Dr. Kathy Halvorsen y Dr. Alex Mayer. Puede usted contactarlos directamente ó si usted lo prefiere, puede contactarme a mi en cualquier momento si tiene usted alguna duda o pregunta relacionada con esta entrevista. Le agradecemos de antemano su participación en este proyecto.

Appendix C: Interview questions

Water manager interview questions (English)

A. Personal Water Data and Belief Questions

1) How long have you lived/worked in Sonora? (for CEA, CONAGUA…)

2) Can you tell me a little bit about the work you do? How far did you go in school?

3) Do you think people in your community have enough water? Is it clean? Any issues?

4) Where does your water come from (city, well, river surface)?

5) What do you mainly use water for?

B. Water Management Questions

6) How much water do you think you use daily (approximately)?

7) Do you think there are major water problems in your community in Sonora? (quality, quantity) How concerned are you?

8) Is Sonoran water well managed? (If not) How do you think it could be improved?

9) Are you familiar with (other) government projects/water management strategies? (If yes) Can you tell me about them?

C. Modeling Questions

10) Are you familiar with the term hydrological modeling? (If yes) What do you think watershed models are used for/ how do they work?

11) (for gov.) Have you ever used watershed models as management tools before? (If yes) For what?

12) Do you believe that watershed models would be useful for water management in Sonora? Why or why not?

13) (for gov.) Would you use/support the use of a watershed model as a management tool in the Sonora River Basin? Why or why not?

D. Climate Change Impact Questions

14) Are you familiar with the term climate change? (if yes) Can you tell me what you know about the issue?

15) Do you think climate change will cause problems in Sonora? What kinds? (do you think there will be any impact on Sonoran water resources?)

16) Who is responsible for understanding and managing for the effects of climate change with regard to water resources? (Government? Which agency?) Who should be responsible?

17) Are you optimistic about water management in Sonora? (Do you think it is currently working or can be fixed?)

User interview questions (English)

A. Personal Water Data and Belief Questions

1) How long have you lived/worked in Sonora?

2) Can you talk a bit about what you do for a living?

3) Do you think people in your community have enough water? Is it clean? Any issues?

4) Where does your water come from (city, well, river surface)?

5) What do you mainly use water for?

B. Water Management Questions

6) How much water do you think you use daily (approximately)?

7) Do you think there are major water problems in your community in Sonora? (quality, quantity) How concerned are you?

8) Is Sonoran water well managed? (If not) How do you think it could be improved?

9) (for users) How often do you think people in the community discuss water issues?

10) Are you familiar with government projects/water management strategies? (if yes) Can you tell me about them?

C. Modeling Questions

11) Are you familiar with the term watershed modeling? (if yes) What do you think models are used for/ how do they work?

12) Do you believe that watershed models would be useful for water management in Sonora? Why or why not?

D. Climate Change Impact Questions

13) Are you familiar with the term climate change? (if yes) Can you tell me what you know about the issue?

14) Do you think climate change will cause problems in Sonora? What kinds? (do you think there will be any impact on Sonoran water resources?)

15) Who is responsible for understanding and managing for the effects of climate change with regard to water resources? (Government? Which agency?) Who should be responsible?

16) Are you optimistic about water management in Sonora? (Do you think it is currently working or can be fixed?)

E. Demographics

17) How far did you go in school?

Water manager interview questions (Spanish)

A. Datos y observaciones personales sobre el agua

1) Durante cuanto tiempo ha vivido en Sonora y por cuanto tiempo ha trabajado en esta organización?

2) Puede describirnos brevemente el trabajo que usted hace en esta organización? Cual es el nivel de su educación?

3) Usted considera que las personas en su comunidad tienen suficiente agua para cubrir sus necesidades diarias? Considera que el agua a la que tienen acceso los usuarios es de buena calidad? Conoce usted algún problema asociado con el agua?

4) De donde proviene el agua que usted tiene en su casa? Del río, de un pozo personal, de la que provee la ciudad de Hermosillo?

5) Podría usted compartir algunos de los usos principales del agua en su casa?

B. Administración del agua

6) Approximadamente cuánta agua usa diariamente para satisfacer sus necesidades?

7) Usted cree que haya problemas con el agua en su comunidad tales como problemas de calidad o de cantidad? Le preocupan esos problemas?

8) Usted cree que el manejo del agua es eficiente? Si usted considera que el manejo del agua no es idóneo, como cree usted que se pueda mejorar?

9) Está usted familiarizado con algún otro tipo de proyecto relacionado a la administración del agua que actualmente está siendo planeado ó implementado por otra agencia gubernamental? Si éste es el caso, puede usted describirnos brevemente ese proyecto ó proyectos?

C. Preguntas de modelos hidrológicos

10) Está usted familiarizado con los modelos hidrológicos? Si es así, como cree usted que funcionen los modelos? Para que cree usted que son utilizados principalmente?

11) Ha utilizado modelos hidrológicos en algún momento de su carrera como una herramienta de trabajo para administrar el agua más eficientemente? Si es así, cual fué el principal objetivo de utilizar éste modelo(s)?

12) Cree usted que los modelos hidrológicos son herramientas de trabajo que son útiles para la administración del agua en Sonora? Por qué?

13) Usaría usted algún modelo hidrológico como herramienta de trabajo para administrar más eficientemente el agua en la Cuenca del Rio Sonora? Por qué?

D. Preguntas sobre el cambio climático

14) Está familiarizado con el término "cambio climático"? Puede decirnos a que se refiere dicho término?

15) Cree que el cambio climático va a impactar a Sonora? Si es así, como cree usted que va a afectar a Sonora, por ejemplo cree usted que la disponibilidad de agua va a disminuir?

16) Quién cree usted que es la agencia o la persona responsable en Sonora para entender y enfrentar los impactos en la disponibilidad del agua asociados con el cambio climático?

17) Está usted satisfecho con el actual manejo del agua ó usted cree que podría ser mejorado?

User Interview Questions (Spanish)

A. Datos y observaciones personales sobre el agua

1) Durante cuanto tiempo ha vivido en Sonora y por cuanto tiempo ha trabajado en esta ciudad?

2) Puede describirnos brevemente en que trabaja?

3) Usted considera que las personas en su comunidad tienen suficiente agua para cubrir sus necesidades diarias? Considera que el agua a la que tienen acceso los usuarios es de buena calidad? Conoce usted algún problema asociado con el agua?

4) De donde proviene el agua que usted tiene en su casa? Del río, de un pozo personal, de la que provee la ciudad de Hermosillo?

5) Podría usted compartir algunos de los usos principales del agua en su casa?

B. Administración del agua

6) Approximadamente cuánta agua usa diariamente para satisfacer sus necesidades?

7) Usted cree que haya problemas con el agua en su comunidad tales como problemas de calidad o de cantidad? Le preocupan esos problemas?

8) Usted cree que el manejo del agua es eficiente? Si usted considera que el manejo del agua no es idóneo, como cree usted que se pueda mejorar?

9) Qué tan seguido cree usted que la gente en su comunidad habla de los problemas asociados con el agua?

10) Está usted familiarizado con algún proyecto relacionado a la administración del agua que actualmente está siendo planeado ó implementado por alguna agencia gubernamental? Si éste es el caso, puede usted describirnos brevemente ese proyecto ó proyectos?

C. Preguntas de modelos hidrológicos

11) Está usted familiarizado con los modelos hidrológicos? Si es así, como cree usted que funcionen los modelos? Para que cree usted que son utilizados principalmente?

12) Cree usted que los modelos hidrológicos son herramientas de trabajo que son útiles para la administración del agua en Sonora? Por qué?

D. Preguntas sobre el cambio climático

13) Está familiarizado con el término "cambio climático"? Puede decirnos a que se refiere dicho término?

14) Cree que el cambio climático va a impactar a Sonora? Si es así, como cree usted que va a afectar a Sonora, por ejemplo cree usted que la disponibilidad de agua va a disminuir?

15) Quién cree usted que es la agencia o la persona responsable en Sonora para entender y enfrentar los impactos en la disponibilidad del agua asociados con el cambio climático?

16) Está usted satisfecho con el actual manejo del agua ó usted cree que podría ser mejorado?

E. Preguntas demográficas

17) Cuál es su nivel de educación?