Engaging The Public And Decision Makers In Cooperative Modeling For Regional Water Management

By: **Kristan Cockerill**, Vincent Tidwell, Lacy Daniel, & Amy Sun

Abstract

In cooperative modeling projects, a group of people work together to develop a model to better understand a complex system and explore consequences of various "what if" scenarios. This report describes a case study from New Mexico in which representatives from diverse organizations and institutions employed system dynamics–based cooperative modeling enhanced by computer-supported cooperative work (CSCW) to design a model that could be used as a tool in making water management decisions. In this case, CSCW was necessitated by the geographically dispersed nature of the participating stakeholders. The case study reflects that, although it is no panacea, cooperative modeling can be a successful way to create a sense of community, even among geographically dispersed citizens and decision makers, to understand contentious and complex water management issues. The purpose of this article is to highlight lessons learned for applying cooperative modeling with CSCW to assist other practitioners and broaden possibilities for improved water management decisions.

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In cooperative modeling projects, a group of people work together to develop a model to better understand a complex system and explore consequences of various "what if" scenarios. This report describes a case study from New Mexico in which representatives from diverse organizations and institutions employed system dynamics–based cooperative modeling enhanced by computer-supported cooperative work (CSCW) to design a model that could be used as a tool in making water management decisions. In this case, CSCW was necessitated by the geographically dispersed nature of the participating stakeholders. The case study reflects that, although it is no panacea, cooperative modeling can be a successful way to create a sense of community, even among geographically dispersed citizens and decision makers, to understand contentious and complex water management issues. The purpose of this article is to highlight lessons learned for applying cooperative modeling with CSCW to assist other practitioners and broaden possibilities for improved water management decisions.

Computers as an analytical tool and collaboration as a method have become intertwined in managing our physical and social systems. This confluence offers benefits and challenges for attempts to manage natural resources. In this case study, the authors describe a system dynamics–based cooperative modeling project designed to develop a model that stakeholders trusted to be used in a future decision-making venue.

The project originated with a United States (US) federal settlement that awarded water from the Gila River Basin to New Mexico and charged the state to reach a decision on how to use the "new" water by 2014. Therefore, the project was designed to meet the state of New Mexico needs rather than as a research effort. Projections suggest that the affected area will experience continued population growth and subsequent development [Bureau of Business and Economic Research (BBER), 2008]. Additionally, the Gila River is the last free-flowing river in the state and therefore offers significant ecological benefits to the region. The diverse and potentially competing interests involved in making this water management decision suggested that collaborative modeling could be a valid method for identifying options.

This case study had several unique features compared to other cooperative modeling projects. First, the team members were dispersed geographically and represented diverse interests from federal, state, and city government, nonprofit groups, and the general public. Second, the core project spanned more than three years, which is extremely long-lived for cooperative modeling. Finally, coordinating the geographically dispersed group over this long time frame required integrating elements of computer-supported cooperative work (CSCW) in several ways, including using Web-based software to enable *virtual* meetings. While virtual meetings themselves are not unique, the project reported here may be the first cooperative modeling effort to employ this approach.

Cooperative Modeling

Cooperative modeling employs principles of collaboration with attempts to link physical and social relationships in a computer model to improve our understanding of com-

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plex systems. In collaborative modeling, participants engage in dialogue, identify key variables and the causal relationships among these variables, identify relevant data, and potentially construct a computer model that helps participants "see" the complexity inherent in the system being studied (Palmer, Keyes, and Fisher, 1993; Rouwette, Vennix, and van Mullekom, 2002; van den Belt, 2004; Vennix, 1999).

Cooperative modeling is not synonymous with collaborative management. Although built in a collaborative fashion, once built, the model itself could be applied in a noncollaborative decision-making process (Cockerill et al., 2009). In the case reported here, the cooperative modeling group was tasked to develop a tool to be employed in a future and separate decision-making process. Many of the individuals, however, who participated in developing the model will also be involved in the decision-making process.

Cooperative modeling is also distinct from processes that bring an existing model to a public and/or decision-making venue to help people understand some issue. In cooperative modeling, participants design models from scratch. In their review, Rouwette, Vennix, and van Mullekom (2002) found that participants do gain more insight into the system if they help construct a model, compared to simply using an existing model.

Like many cooperative modeling projects, this one used a system dynamics platform. As its name implies, system dynamics seeks to explicate the dynamic nature of complex systems. "It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static snapshots, and for seeing processes rather than objects" (Simonovic and Fahmy, 1999, p. 295). Key to system dynamics is explicitly describing the "mental model" of a system by drawing causal loop diagrams that show how variables affect each other. These loops form the model frame that is then populated with relevant data. Computer-based system dynamics has been applied to diverse business and environmental management issues (Cockerill, Passell, and Tidwell, 2006; Costanza and Ruth, 1998; Forrester, 1961; Moxey and White, 1998; Palmer et al., 1999; Stave, 2003; Sterman, 2000; Tidwell et al., 2004; van den Belt, 2004; van Eeten, Loucks, and Roe, 2002).

A broad array of team and process structures can be used in cooperative modeling. Some projects are completed in a single meeting, whereas others are multiyear endeavors. The models themselves can vary from small (five variables) to quite large (1000s of variables). Groups are typically multidisciplinary and are often comprised of technical professionals from disciplines relevant to the system being studied. Less often these groups include representatives from the general public and/or decision makers. Any group requires modelers who can write the code for the computer model. Many groups employ a facilitator and/or a note taker. In the case reported here, the authors are either employed by or are consultants to Sandia National Laboratories (hereafter, Sandia) and include the project leader, the primary modeler, the facilitator, and the note taker.

Most documented cooperative modeling efforts occur in face-to-face meetings. Many water management issues, however, are regional and involve geographically dispersed stakeholders. This was the situation in this New Mexico case where key stakeholders were separated by more than 300 miles. Computer technology enables virtual meetings to allow dispersed participation.

Computer-Supported Cooperative Work

More than 20 years ago, researchers began to explore how computers could be used in the workplace and coined the term *computer-supported cooperative work* (Crabtree, Rodden, and Benford, 2005; Greif, 1988; Grudin, 1994). Since then, CSCW has been used to meet various needs and includes electronic meeting systems and decision-support systems. At an advanced level, the technology enables distributed, synchronous work, which allows geographically separated individuals to work on a project simultaneously (Bidarra et al., 2002; Chen, Song, and Feng, 2004; Dean, Orwig, and Vogel, 2000; Sarjoughian and Zeigler, 1999; van den Berg, 2000).

At a less integrated level, CSCW uses computers to mediate face-to-face meetings or to enable regular interaction among geographically dispersed individuals. These efforts can be asynchronous, where individuals work independently (in space and time), or synchronous, where everyone works simultaneously. Like cooperative modeling, CSCW goals include using the technology to encourage collaboration, generate synergy and hence improve the overall effort and/or product (Dennis, 1996; Garner and Mann, 2003; Leinonen, Järvelä, and Häkkinen, 2005; Zigurs, Poole, and DeSanctis, 1988).

The results are mixed as to whether CSCW is as effective as face-to-face gatherings. In much CSCW, participants simultaneously contribute to a discussion. This allows many ideas to be generated and prevents a loss of input due to the time lag while waiting for others to speak or due to pressure to mesh with the majority opinion (Dennis, 1996; Nunamaker et al., 1991). Many CSCW efforts allow participants to remain anonymous, and some evidence suggests that, without social cues about power structures, groups can generate more ideas, achieve a higher rate of information exchange, and consider a wider range of alternatives (Flanagin et al., 2002; Lemus et al., 2004; Scott, 1999). On the other hand, computer-aided communication can take longer because the nonverbal communication cues are missing, and some studies show that decision paths are not significantly different from non-computer-assisted face-to-face meetings (Dennis, 1996; Poole and Holmes, 1995; Scott, 1999).

Despite potential pitfalls, computer-based interaction is an important alternative to face-to-face gatherings. This technology can help to acquire local knowledge to ensure diverse participation on projects that cover a large geographic space, as was the situation in this case study.

Gila–San Francisco Cooperative Modeling Project

Cooperative Framework

This case began with a US federal water settlement regarding the Gila River Basin (Figure 1). In December 2004, the Arizona Water Settlements Act (hereafter, Settlement) provided New Mexico with 14,000 acre-ft per year (calculated on a 10-year average) and funding to be used for a water supply project, environmental mitigation, or restoration activities associated with a project. The Settlement tasked the New Mexico Interstate Stream Commission (NMISC) in consultation with a regional planning group with deciding how to apply the Settlement. The NMISC requested that personnel from Sandia assist the state to develop tools to support the decision-making process.

The authors worked with representatives from the NMISC and the regional planning group to establish the Gila–San Francisco Modeling Team. (The San Francisco River is a primary tributary to the Gila River in New Mexico.) This group is one element of a larger program to study options for the Settlement. To manage the planning effort, the NMISC established the Gila–San Francisco Coordinating Committee (GSFCC). Under the umbrella of the GSFCC were several groups, including a public involvement subcommittee, a technical subcommittee, and the modeling team described in this report (Figure 2).

Team Composition

Thirteen individuals (including two of the authors) from 10 institutions and organizations representing federal, state,

Figure 1. Map of the region featured in this case study.

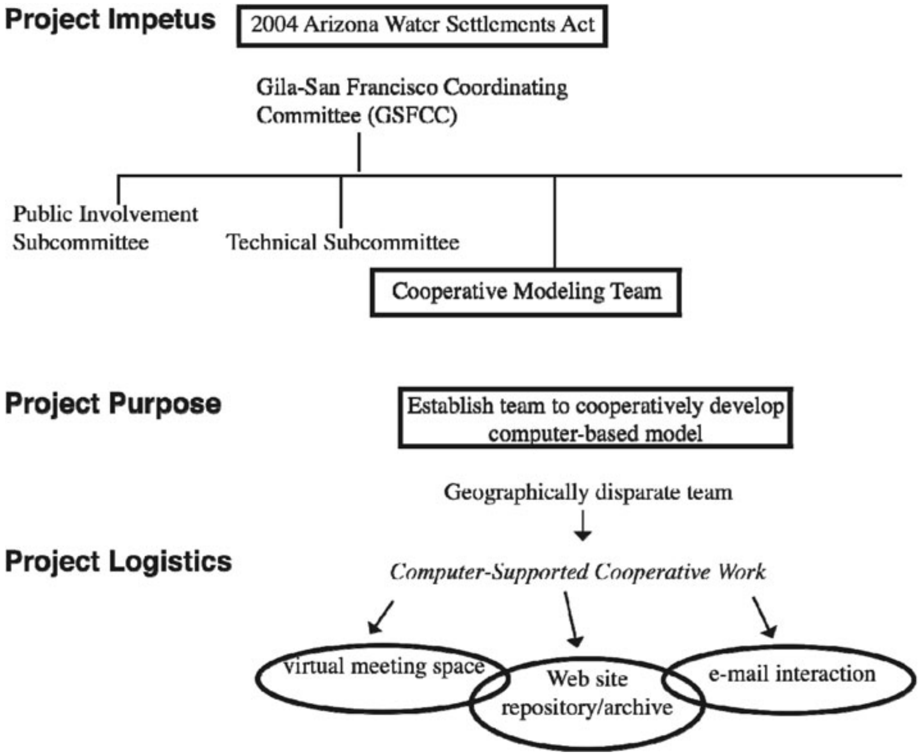

Figure 2. The modeling project was prompted by a federal settlement and was part of a broader planning effort. The group's purpose was to develop a tool and relied on a number of computer aids to complete this task.

and local government agencies, as well as environmental nonprofit groups and members of the general public, attended a kickoff meeting in September 2005. The team agreed that although the key regional interests were present, they would continue to strive for even better representation. Between 2005 and 2007, the team had representation from 11 different government agencies, public-interest organizations, and the general public. Throughout the project, the specific individuals participating did change, especially for the state and federal agencies, but diversity among interests remained stable. The facilitator maintained a *team roster* that reflected the group's consensus on who was included as a member. This list was used to send meeting announcements and other information.

Throughout this project, the authors stressed that all team members were working together toward a common goal of designing a model that could be used in a future decision-making process. Although everyone on the team roster was considered a team member, there were divisions of labor within the group. The authors represent the *project leaders* and were responsible for coordinating meetings, maintaining communication, and integrating ideas and information into the computer model. The *decision makers* were the state-level institutions responsible for making the eventual water management decision. The other members represented key interests (e.g., environmental groups, resource management groups, local governments, and the general public) and were responsible for identifying data and ensuring that the model accurately represented the relationships relevant to managing water supply and demand in the region.

Meetings

Because members of the Gila–San Francisco Modeling Team were geographically dispersed, the authors established a virtual meeting structure by using the commercial product, WebEx, and separate teleconferencing technology. WebEx links desktop computers, which can be located anywhere, so that meeting participants share a computer interface. (The Sandia license allows 15 computers to connect.)

Between October 2005 and June 2007, the modeling team met every other week for 2 h via WebEx, with less frequent meetings occurring over the subsequent 18 months as the model matured.

Early meetings focused on process issues, including establishing team ground rules and a communication plan to enable information to be disseminated from the modeling group. The majority of meetings focused on reviewing elements of the model and discussing whether the causal relationships were accurate, what variables were missing, and ideas for data sources. Specifically, the team employed a four-step modeling process:

- Define the problem and the scope of analysis.
- Describe the system being modeled and develop causal loop diagrams for system sectors (e.g., agriculture, mining).
- Populate system sectors (derived from the causal loop diagrams) with appropriate data and mathematical relations.
- Assess the model against historical data.

In addition to the virtual meetings, there were nine face-to-face meetings. These were highly productive and helped to keep the team focused on project goals. In these meetings, the authors gained assistance in debugging the model as team members "played" with the tool and offered feedback. Comments from the team indicated that these sessions offered the best approach for them to actually understand the model.

Intermeeting Work

Immediately following each meeting, there was a brief discussion among the authors. Additionally, the facilitator would send e-mails identifying concerns with group dynamics or suggestions for addressing topics that had become contested. Between meetings, the facilitator and the note taker generated notes and posted these to the project Web site. The facilitator often conversed with team members between meetings about various aspects of the project or to provide an update for people who had missed a meeting. The authors gathered, reviewed, and integrated data between meetings, as well as constructed the model. There were also teamwide e-mail exchanges from time to time on various issues. For example, in June 2006, one member sent an article discussing ecological policy decisions. This prompted a lengthy and comprehensive online exchange about the nature of collaborative efforts, the reality of decision making, and the relevance of these ideas to this modeling project.

Some members dug deeper into project data. For example, after the team raised questions about incongruities in river-discharge data, one member began actively tracking the data and contacted individuals at various agencies to try to understand why a significant amount of water seemed to "disappear." His research enabled the team to reach a decision on how to better conceptualize the surface and groundwater systems and their interaction.

Model Structure

The entire team was responsible for defining the context and structure of a system dynamics model. The framework was based on three questions that the group identified early in the process:

1. Given various constraints, how much water is available from where, when, and to what purpose?
2. Given various constraints, how much water is in demand from where, when, and to what purpose?
3. What are the trade-offs among various approaches to managing this water?

Additionally, the group identified variables over which they wanted control in the model. These became the foundation for user-interface development: demand by category (residential, agricultural, domestic, industrial); instream flow targets; population change; and weather/climate (temperature, precipitation, climate change).

Likewise, the team identified key metrics that they wanted as output: river discharge by reach as influenced by diversions and legal constraints, water appropriated versus actual use, water in storage (e.g., groundwater), management effects on water supply/demand, and effects on aquatic/riparian species and river ecology.

The model is structured according to five broad sectors: surface water, groundwater, institutional controls, environmental, and water use. Model simulations are conducted on a daily time step over a variable planning horizon. Spatially, the model is disaggregated according to river reaches as defined by eight active gauging stations.

The surface-water system considers the Gila and San Francisco Rivers. Flow between gages is routed by a time-delay coefficient based on the river discharge. Gains to the river include tributary inflows, groundwater gains, and agricultural return flows. River losses include groundwater leakage and evaporation. Diversions from the river include water for irrigated agriculture (all reaches) and for mining (one reach).

Two groundwater aquifers, one fluvial and one regional, accompany each river reach. Groundwater flows are modeled between adjoining reaches, between the fluvial and regional aquifer, and between the river and fluvial aquifer. Flows are driven by differences in hydraulic head. Gains to the regional aquifer are limited to distributed recharge, whereas losses include municipal/agricultural pumping and losses to the fluvial aquifer. Fluvial aquifers receive inflow from irrigation seepage, irrigation canal leakage, and the regional aquifer, whereas losses occur by riparian evapotranspiration, pumping, and river discharge.

There are three institutional controls in the Gila River Basin. A compact with neighboring states limits total water consumption in the basin. Additionally, a system of senior water rights constrains water delivery priorities throughout the basin. Finally, the Consumptive Use and Forbearance Agreement (CUFA) stipulates when, how much, and where Settlement water can be taken. These controls are implemented in the model.

The model addresses the extent and composition of the riparian vegetation and then tracks its impact on the available water supply. Aquatic habitat is primarily addressed by tracking various flow targets at critical subreaches within the basin. Both low flow and flood target levels are tracked.

Temporally varying water demands are calculated for four basins (Gila, San Francisco, Mimbres, and Animas) where residents are potential recipients of Settlement water. Specific demands include agricultural, livestock, industrial, mining, and commercial or residential. Agricultural demands are modeled as a function of the crop, acreage, climate, and adjudicated water right. Livestock demand is calculated according to the type of operation (farm vs. open range), number of cattle, and the water right. Industrial and mining uses are modeled according to past uses and their adjudicated right. Municipal and commercial uses are modeled according to population, per-capita use, and the adjudicated water right. Water uses in each case are modeled individually for each municipality and by county for domestic well users.

A user interface was developed to allow people to interact directly with the tool. User control categories include Hydrograph and Temperature, CUFA, Municipal Demand, Agriculture, Minimum Flow, and Mining Leased Water Rights.

In Hydrograph and Temperature, users can change tributary inflows and atmospheric temperature. The perturbations in either category do not currently map to a specific climate scenario but a mere sensitivity analysis. The CUFA category controls the initial conditions for the CUFA implementation and users can turn the diversion *on* or *off* for the Gila River or San Francisco River. In the Population category, users can set population growth rates in the region, change per capita water use, and/or the percentage of water rights used (not all rights are exercised every year). Within Agriculture, users can adjust the amount of irrigable land and cattle population growth or decline. The Minimum Flow category allows users to control target flows by river reach and season. The Mining interests own a large percentage of the water rights in the region but rarely exercise all these rights; rather, water is generally leased to irrigators or municipalities, and model users can adjust these leases.

For a more detailed discussion of the model, see Sun et al. (2008, 2009).

Results and Lessons Learned

The primary goal of this project was to develop a model that could be used in a future decision-making process regarding the Gila River Basin. That was accomplished. The project was also an opportunity to contribute to the knowledge base of how to use cooperative modeling in water management venues. Toward that end, this section summarizes the broad types of issues that we encountered in this case study that are likely to be present in other cooperative modeling efforts. It also summarizes data from surveys of modeling team members regarding the project.

Contested Issues

Throughout the project, there were several debates that occupied at least one meeting and/or were raised multiple times. These generalized topics (model purpose and boundaries, data, and sharing project information) are relevant to any cooperative modeling effort involving the public and a contentious issue.

Model purpose and boundaries

The group spent hours discussing the model's purpose and capabilities. Despite frequent explanations that system dynamics is designed to show trends, not to make predictions, team members repeatedly raised the question of whether the model would be predictive at a specific level (e.g., specific water flow at a specific place and time). The detailed notes from all team meetings were helpful here to remind the team what had been defined and decided previously.

What the model would include and exclude (i.e., its boundaries) was discussed thoroughly. Many of these issues were resolved as the group worked through diagramming the causal relationships. Questions about the ability to add functionality at some future time, however, became a repetitive topic. Most specifically, some team members asked numerous times whether economic information and more complex population data could be added in the future. These discussions reflected concerns about the relationship between projected development in the region and ensuring that the model, as well as policy decisions, would reflect the region's demographic status. The authors repeatedly assured the group that it is feasible to expand the model in the future.

Data

The team spent significant time discussing both the availability and the reliability of data. In particular, there was much discussion about meteorological data, the accuracy of available precipitation data, and the calculations for evapotranspiration. Some team members also raised concerns related to limited data, as well as lack of participation from the mining industry. Although a mining representative participated in early meetings, requests for data were largely ignored. Much of the information about mine water use came from nonmining group members. This reflects the value of tapping local sources of knowledge.

Concerns about lack of data or its reliability raised questions about whether the model would be accurate enough to be useful. At times, team members reluctantly agreed that additional data collection was beyond the scope of this modeling project, but they sought to ensure that the data gaps were documented as part of the model development process so that this information would be available in the later decision-making process.

Sharing information outside the team

One of the most contentious discussions was how and when members could share model information and/or results from the draft models with individuals not involved in the modeling project. There were two specific issues. First, there was concern that preliminary information may not be solid enough to stand up to scrutiny, which would discredit the model and the process. Second the discussion raised underlying issues of trust among various members and their constituents. The group was able to resolve this issue through open, though at times volatile, discussion. The authors returned to the ground rules and communication plan in order to emphasize the previous agreement to clearly denote material as *draft* and to discuss any outside presentations with the team. The intensity of the concerns highlighted varying levels of trust among members and the broader community; however, the resulting discussions served to develop a stronger shared experience within the group.

Interviews and Surveys

The facilitator and note taker conducted interviews with team members in 2005 to gain a sense of various perspectives on the modeling project at its outset. Key findings included that individuals had not internalized the idea that they were going to help design the model, but rather they perceived that this was a model that Sandia had already developed or would develop, which the group simply approved. Second, there were misperceptions about what other team members would say in their interviews. Most specifically, several members were convinced that other members would push strongly for damming the Gila River. Yet, the majority of the interviewees stated that building a dam was highly unlikely. The facilitator posted anonymous interview summaries on the project Web site and used this information early in the process to begin to develop a shared sense of purpose and community.

To gather more quantitative data, two anonymous surveys were administered: one in July 2006 and one at the end of the model development phase in June 2007. The 2006 results showed general satisfaction with the process, but respondents were reluctant to say anything about the model itself because they had not yet seen a complete version that integrated the various components.

Once the team had an opportunity to play around with the model, the authors repeated the assessment. There were few differences between the surveys. A third survey conducted as part of a graduate thesis drew similar conclusions (Franky, 2008).

Table 1 shows the mean responses for the 2006 and 2007 assessments. The response rate was high, as the number of respondents does reflect average attendance (excluding the authors) at meetings for several weeks surrounding each

Table 1. Gila–San Francisco Modeling Team survey results in 2006 and 2007, using a scale of 1 (Strongly Agree) to 5 (Strongly Disagree)

Statement	July 2006 Mean (n = 13)	July 2006 *SE*	June 2007 Mean (n = 9)	June 2007 *SE*
Cooperative modeling process				
Team members represent the key interests and concerns in the Southwest region.	2.3	.208	2.4	.377
Team members bring specialized knowledge that would otherwise not be readily available to the modelers.	2.1	.178	1.7	.236
I have sufficient opportunity to present my ideas and raise questions.*	1.9	.104	1.6	.183
The modelers are responsive to my concerns and questions.	2.2	.296	1.6	.183
Meetings are well organized.*	1.9	.077	1.7	.167
This collaborative, multidisciplinary approach is a more effective way to design a useful model than having modelers design alone.	1.6	.180	1.3	.236
Computer-supported cooperative work				
The "virtual" meeting format is appropriate for this project.	1.8	.166	1.6	.294
The frequency of face-to-face meetings is sufficient for this project.	3.1	.260	2.7	.333
Using Webex is easy.	2.2	.122	2.2	.278
I would encourage other collaborative modeling teams to use Webex.	2	.253	2.1	.200
Projects like this should have a Web site for posting data, notes, and other information.	1.7	.133	1.6	.176
I have used the Web site consistently during this project.*	2.9	.348	2.7	.289
The model				
I believe the model will capture the key trends in this region relevant to the Arizona Water Settlements Act.	2.5	.215	2.5	.189
I expect the model to identify relationships related to water supply and demand that were not apparent without the model.*	2.3	.263	2	.167
I believe the model will be a useful tool in making a decision about the Arizona Water Settlements Act.	2.4	.266	2.3	.236
I believe the model will be an appropriate tool to use in public meetings about the Arizona Water Settlements Act.	2.5	.215	2.6	.176

Items marked with an *asterisk* show significant difference at .05 or lower between the two surveys using Levene's test for equality variance; *t* tests show no significant differences.

survey. The lower response rate in 2007 is due to two reasons. First, a natural loss of participation is expected in a long-term effort. Second, there were structural changes in the GSFCC, which meant that several state-level decision makers who responded in 2006 did not respond in 2007. The survey covered three broad categories, which are explicated in more detail below: (a) the cooperative modeling process, (b) CSCW as a logistical aid to the collaborative modeling approach, and (c) the model itself.

The cooperative modeling process

Team composition and participation. Overall, this team enjoyed a positive, harmonious working relationship. The self-selecting nature of participation likely influenced this positive outcome. Although the team recognized that not all interests were consistently represented, survey results indicate that the group felt they did adequately reflect most of the key interests in the region.

Meeting attendance was excellent during model development and averaged 16 people (including the authors) at meetings in 2005–7. This high level of attendance may be due to the ease of the virtual technology, as meetings were held early in the morning before the workday. One potential participation issue was 15-computer restriction. Team members who were geographically colocated did share computers to ensure that everyone had access. There were, however, a few meetings in which all 15 slots were used, leaving some potential attendees without computer access, although they could still join the teleconference and were counted as attending.

Meetings were characterized by strong participation, with numerous questions and discussion points raised in each session. There were several fairly volatile meetings, and one person left the team in 2006 during a particularly contentious discussion about sharing information from the modeling project outside the team. Although conflict can be productive in identifying core values, it does make people uncomfortable (Lindblom, 1990; Putnam, 1986). In this modeling project, some members would step in to mediate an argument earlier than the facilitator would have liked. This restored calm but may have also reduced the ability to clearly identify and address root concerns. On the other hand, the survey results reveal that there was support for the model developed, so the conflict and its resolution seem to have been effective. Establishing ground rules and a communication plan early in the process helped to ensure that the group could weather such debates successfully.

This modeling project relied heavily on local knowledge. Throughout the project when reviewing the various causal loop diagrams or model components, members were able to identify errors and to clarify causal relationships. Additionally, the group generated more than 70 suggestions for data sources relevant to the model design. The level and diversity of input were well beyond what the modelers would likely have achieved by themselves. To ensure relevance and accuracy, the modelers did review suggested data sources and confirmed team-member knowledge about specific issues before using the information.

Gathering local knowledge does take time and requires that the model development process remain flexible. As someone noted in the 2006 survey, it is good to have an agenda but not always follow it. Integrating local knowledge into the process often meant exploring ideas and concerns that were not on the agenda. This requires dedicating the requisite time but does increase confidence in the process and eventual product.

Additionally, while accessing local knowledge is crucial in any participatory effort, it is important to not assume anything specific about local knowledge. For example, in preparing for the kickoff meeting, the authors assumed that the regional water planning group would be intimately familiar with the Settlement and this proved to be not true. Therefore, in early meetings, the authors spent more time than originally planned explaining the Settlement and its implications.

By mid-2007, the model was available for team members to use. Only a couple of individuals, however, really explored it between meetings. This reflects at least two things. One, the model is large and requires an up-to-date computer to function well, and without a modeler to serve as a guide it is not entirely intuitive. Additionally, group members agreed early in the project that while those members representing area interests would offer suggestions for data sources and would review the model as it was developed, Sandia personnel should take a strong leadership role in gathering and interpreting data and actually building the model components between meetings.

Decision-maker participation. Sheen, Baeck, and Wright (1989) note that decision makers tend to reject models that they do not understand. Ford (1999) echoes this and states, “Models should not be constructed in isolation from the people who will use them to deal with a serious problem” (p. 171). Therefore, it is highly desirable to include decision makers in the cooperative modeling process. This can be problematic, however, as Rotmans and Dowlatabadi (1998) discuss. There is the political reality that the people charged with actually making a decision need to support and believe in the final product or it will not be used. Having these individuals participate in the modeling project offers the opportunity to ensure that they buy into the process and the product. On the other hand, there is the tendency for the decision makers to reject ideas that are perceived to be politically unpalatable or to request a level of sophistication and/or certainty that is unrealistic (Pilkey and Pilkey-Jarvis, 2007). Ford (1999) also notes, “Models are most useful when they lead to ‘counterintuitive’ results, which force planners to reexamine their intuitive understanding of the system” (p. 5). When particular variables or relationships are discounted before being entered into the modeled system, the group can lose the opportunity to find some of these counterintuitive results.

This project did encounter some scope-limiting behavior from the decision makers. In one example, state agency participants opposed including specific management scenarios in early model drafts. The concern was that if specific management alternatives were included, people outside the modeling team could interpret these as “preferred options,” which would have been premature within the overall decision-making time frame. Even though the model was not yet available to anyone outside the modeling team, the group decided to wait until there was a venue with broader input to develop alternatives to be included in the model. This may or may not have limited insight that the group could have gained from exploring the scenarios.

On the positive side, the state-level decision makers participating in this project were helpful in educating other team members about legal details in the Settlement and about state water management. They were also helpful in explaining specific procedural aspects of the decision effort, in particular issues related to various constraints on water use and various ecological studies required as part of the actual decision process. The state agency members were instrumental in reminding the group that this model was only one aspect of a separate decision-making process and that this would not be a *technocratic* water management decision.

This project did experience some fallout from political decisions. In early 2007, the New Mexico governor vetoed an appropriation for Gila River Basin water development. This halted funding for many aspects of the Settlement decision process. For the modeling team, this meant reduced participation from state-level officials for several months.

In October 2007, efforts to reinvigorate the larger planning process were initiated through a series of public workshops. The new planning process mandates open and inclusive collaborative planning. The initial planning group (GSFCC) was replaced by the Arizona Water Settlement Act Planning Group. Due to the lengthy reorganization process, funding limitations, and contracting issues, cooperative modeling efforts were limited throughout 2008 and much of 2009. Efforts focused largely on educating the new planning group about the model and its value in the eventual decision-making process. In late 2009, the team initiated monthly meetings, working toward final model calibration and constructing and simulating key scenarios for the planning group.

Assistance from CSCW

The CSCW components were integral to this case. The Web site helped manage the tremendous volume of information generated and established an archive for the team. Survey responses indicated that although team members did not use the Web site consistently, they believed that it was necessary to ensure an open, available process. The facilitator used the archive frequently to remind team members of previous discussions and decisions, which helped to maintain focus.

Employing the virtual meeting technique made this project feasible, and, as the survey results show, team members agreed that the technology was appropriate and fairly easy to use. The physical distance among team members precluded bimonthly face-to-face meetings. Computer technology enabled the authors to leverage face-to-face meetings with virtual meetings to enable consistent participation from team members. There are, however, significant disadvantages to the virtual approach. The WebEx venue made it easier for people to be present, yet not fully engaged, at meetings. Because most people used speakerphones, meetings were often accompanied by the sounds of side conversations, typing, and water running. Additionally, the virtual meetings did not allow the use of traditional facilitation techniques, such as body positioning to quiet an overly talkative person or to read body language to identify when someone had something to contribute. It was also impossible to determine whether individuals were becoming uncomfortable with the level of conflict in the discussion until someone interjected. Because nonverbal cues were unavailable, communication often took longer than it might have in a traditional meeting. These factors contributed to survey results recommending more face-to-face meetings. Additionally, team members were more likely to interact with the model in face-to-face meetings.

The model

The surveys indicate support for the model, with some caveats. Several respondents noted “it depends” on survey questions pertaining to the model’s use as an educational and a decision-making tool. Concerns related to novice users who do not possess the context surrounding model content and who, therefore, could misinterpret model results. Other concerns related to more malicious potential to skew model results intentionally to serve some political end.

Conclusions

The Gila–San Francisco Cooperative Modeling project reflects characteristics of any collaborative effort but offers insight into using CSCW in cooperative modeling with public participation. Key lessons include the following:

- Ensuring representation among all interests is difficult; however, CSCW can enable a level of participation that otherwise would be precluded simply because of distance. This contributes to a more robust process and likely to a more reliable and trusted tool.
- A healthy level of conflict can be beneficial, but it does make team members uncomfortable. In this case, the meeting mode (virtual or face-to-face) did not seem to influence the level of conflict. The meeting mode does, however, affect a facilitator’s ability to assess the level of conflict accurately and respond accordingly.

- Local knowledge is invaluable but cannot be assumed. It is important to confirm local knowledge with other sources whenever possible. It is also important to recognize that the project leaders may need to educate cooperative modeling participants about the issue being addressed.

- Cooperative modeling teams need to decide explicitly what level of participation individuals want to have in the process. Teams that elect to make the modelers largely responsible for developing and testing the actual computer model may benefit even more from CSCW because it allows frequent virtual meetings to see the model as it develops.

- Establishing ground rules for team interaction can help navigate rough waters. While this seems to be a commonsense lesson, it is often ignored in collaborative efforts and therefore does need to be emphasized.

- Communication is always a challenge in collaborative projects. Using a broad range of communication tools, particularly Web conferencing, e-mail, file sharing, and face-to-face meetings, provides an extended range of communication options, thus allowing team members to express themselves in ways that best fit their preferences and personality.

Although not painless, this cooperative modeling project was successful. The process that the modeling group used has been adopted for the actual decision-making phase. The conflict during the project did result in a better final product and likely contributed to overall positive results, as reflected in team surveys. This indicates that team members do believe that the computer model has the potential to be used productively in public information as well as decision-making venues to reach a sound decision about this water management issue.

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References

Bidarra, R., N. Kranendonk, A. Noort, and W.F. Bronsvoort. 2002. A Collaborative Framework for Integrated Part and Assembly Modeling. In *Proceedings of the Seventh ACM Symposium on Solid Modeling and Applications*, Saarbrücken, Germany. Association for Computing Machinery, New York, 389–400. Available at http://portal.acm.org/citation.cfm?id=566337 (accessed October 5, 2010).

Bureau of Business and Economic Research (BBER). 2008. *New Mexico County Population Projections: July 1, 2005 to July 1, 2035*. BBER, Albuquerque, NM. Available at http://bber.unm.edu/ (accessed December 2009).

Chen, L., Z. Song, and L. Feng. 2004. Internet-Enabled Real-Time Collaborative Assembly Modeling via an e-Assembly System: Status and Promise. *Computer-Aided Design* 36(9):835–847.

Cockerill, K., L. Daniel, L. Malczynski, and V. Tidwell. 2009. A Fresh Look at a Policy Sciences Methodology: Collaborative Modeling for More Effective Policy. *Policy Sciences* 42(3):211–225.

Cockerill, K., H. Passell, and V. Tidwell. 2006. Cooperative Modeling: Building Bridges between Science and the Public. *Journal of the American Water Resources Association* 42(2):457–471.

Costanza, R., and M. Ruth, 1998. Using Dynamic Modeling to Scope Environmental Problems and Build Consensus. *Environmental Management* 22(2):183–195.

Crabtree, A., T. Rodden, and S. Benford. 2005. Moving with the Times: IT Research and the Boundaries of CSCW. *Computer Supported Cooperative Work* 14(3):217–251.

Dean, D.L., R.E. Orwig, and D.R. Vogel. 2000. Facilitation Methods for Collaborative Modeling Tools. *Group Decision and Negotiation* 9(2):109–127.

Dennis, A.R. 1996. Information Exchange and Use in Group Decision Making: You Can Lead a Group to Information But You Can't Make It Think. *MIS Quarterly* 20(4):433–457.

Flanagin, A.J., V. Tiyaamornwong, J. O'Connor, and D.R. Seibold. 2002. Computer-Mediated Group Work: The Interaction of Member Sex and Anonymity. *Communication Research* 29(1):66–93.

Ford, A. 1999. *Modeling the Environment: An Introduction to System Dynamics Modeling of Environmental Systems*. Island Press, Washington, DC, 415 pp.

Forrester, J.W. 1961. *Industrial Dynamics*, 2nd edition. MIT Press, Cambridge, MA, 479 pp.

Franky, C.E. 2008. Determining Model Robustness within a Collaborative User Framework: The Gila–San Francisco Decision Support Tool (unpublished master's thesis). University of Nevada, Las Vegas, 70 pp.

Garner, S., and P. Mann. 2003. Interdisciplinarity: Perceptions of the Value of Computer-supported Collaborative Work in Design for the Built Environment. *Automation in Construction* 12(5):495–499.

Greif, I., ed. 1988. *Computer-Supported Cooperative Work: A Book of Readings*. Morgan Kaufmann, San Mateo, CA, 783 pp.

Grudin, J. 1994. Computer-Supported Cooperative Work: History and Focus. *Computer* 27(5):19–26.

Leinonen, P., S. Järvelä, and P. Häkkinen. 2005. Conceptualizing the Awareness of Collaboration: A Qualitative Study of a Global Virtual Team. *Computer Supported Cooperative Work* 14(4):301–322.

Lemus, D.R., D.R. Seibold, A.J. Flanagin, and M.J. Metzger. 2004. Argument and Decision Making in Computer-Mediated Groups. *Journal of Communication* 54(2):302–320.

Lindblom, C.E. 1990. *Inquiry and Change: The Troubled Attempt to Understand and Shape Society*. Yale University Press, New Haven, CT, 326 pp.

Moxey, A., and B. White. 1998. NELUP: Some Reflections on Undertaking and Reporting Interdisciplinary River Catchment Modelling. *Journal of Environmental Planning and Management* 41(3):397–402.

Nunamaker, J.F., A.R. Dennis, J.S. Valacich, D.R. Vogel, and J.F. George. 1991. Electronic Meeting Systems to Support Group Work. *Communications of the ACM* 34(7):40–61.

Palmer, R.N., A.M. Keyes, and S. Fisher. 1993. Empowering Stakeholders through Simulation in Water Resources Planning. In *Water Management in the '90s: A Time for Innovation*, K. Hon, ed. Proceedings of the 20th Anniversary Conference of ASCE's Water Resources Planning and Management Division, Seattle, Washington, May 1–5. American Society of Civil Engineers (ASCE), New York, 451–454.

Palmer, R.N., W.J. Werick, A. MacEwan, and A.W. Woods. 1999. Modeling Water Resources Opportunities, Challenges and Trade-offs: The Use of Shared Vision Modeling for Negotiation and Conflict Resolution. In *WRPMD '99: Preparing for the 21st Century*, E.M. Wilson, ed. Proceedings of the 26th Annual Water Resources Planning and Management Conference, ASCE, Tempe, AZ, June 6–9. American Society of Civil Engineers (ASCE), New York, chap. 254.

Pilkey, O.H., and L. Pilkey-Jarvis. 2007. *Useless Arithmetic: Why Environmental Scientists Can't Predict the Future*. Columbia University Press, New York, 230 pp.

Poole, M.S., and M.E. Holmes. 1995. Decision Development in Computer-Assisted Group Decision Making. *Human Communication Research* 22(1):90–127.

Putnam, L.L. 1986. *Conflict in Group Decision-Making*. In *Communication and Group Decision-Making*, R.Y. Hirokawa and M.S. Poole, eds. Sage, Thousand Oaks, CA, 175–196.

Rotmans, J., and H. Dowlatabadi. 1998. *Integrated Assessment Modeling: Human Choice and Climate Change*, S. Rayner and E.L. Malone, eds. Battelle Press, Columbus, OH, 291–377.

Rouwette, E.A.J.A., J.A.M. Vennix, and T. van Mullekom. 2002. Group Model Building Effectiveness: A Review of Assessment Studies. *System Dynamics Review* 18(1):5–45.

Sarjoughian, H.S., and B.P. Zeigler. 1999. The Role of Collaborative DEVS Modeler in Federation Development. In *SISO Fall Proceedings of the Simulation Interoperability Workshop*, Orlando, FL, September 12–17. Simulation Interoperability Standards Organization (SISO), Orlando, FL. Available at http://www.acims.arizona.edu/PUBLICATIONS/SIW99Paper/DEVSOMT-SIW-fall99Final.doc (accessed October 5, 2010).

Scott, C.R. 1999. Communication Technology and Group Communication. In *The Handbook of Group Communication Theory & Research*, L.R. Frey, ed. Sage, Thousand Oaks, CA, 432–472.

Sheen, D.P., M.L. Baeck, and J.R. Wright. 1989. The Computer as Negotiator. *Journal of the American Water Works Association* 81(2):68–73.

Simonovic, S.P., and H. Fahmy. 1999. A New Modeling Approach for Water Resources Policy Analysis. *Water Resources Research* 35(1):295–304.

Stave, K. 2003. A System Dynamics Model to Facilitate Public Understanding of Water Management Options in Las Vegas, Nevada. *Journal of Environmental Management* 67(4):303–313.

Sterman, J.D. 2000. *Business Dynamics: Systems Thinking and Modeling for a Complex World*. McGraw-Hill, Boston, 1008 pp.

Sun, A., V. Tidwell, and G. Klise. 2009. Gila-San Francisco Decision Support Tool. Presented at *The Second Natural History of Gila Symposium*, Silver City, NM, October 16–17.

Sun, A., V. Tidwell, G. Klise, L. Malczynski, W. Peplinski, and J. Brainard. 2008. System Dynamics Model of Southwestern New Mexico Hydrology to Assess Impact of the 2004 Arizona Water Settlements Act. In *Proceedings of the International Conference of the System Dynamics Society*, Athens, July 20–24. Available at http://www.systemdynamics.org/conferences/2008/proceed/index.html.

Tidwell, V.C., H.D. Passell, S.H. Conrad, and R.P. Thomas. 2004. System Dynamics Modeling for Community-Based Water Planning: Application to the Middle Rio Grande. *Aquatic Sciences* 66(4):357–372.

van den Belt, M. 2004. *Mediated Modeling: A System Dynamics Approach to Environmental Consensus Building*. Island Press, Washington, DC, 196 pp.

van den Berg, E. 2000. Web-Based Collaborative Modelling with SPIFF (unpublished master's thesis). Delft University of Technology, Delft, The Netherlands, 55 pp.

van Eeten, M.J.G., D.P. Loucks, and E. Roe. 2002. Bringing Actors Together around Large-Scale Water Systems: Participatory Modeling and Other Innovations. *Knowledge, Technology and Policy* 14(4):94–108.

Vennix, J.A.M. 1999. Group Model-Building: Tackling Messy Problems. *System Dynamics Review* 15(4):379–401.

Zigurs, I., M.S. Poole, and G.L. DeSanctis. 1988. A Study of Influence in Computer-Mediated Group Decision-Making. *MIS Quarterly* 12(4):625–644.