Cooperative Modeling Lessons for Environmental Management

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No Abstract

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COMMENTARY

Cooperative Modeling Lessons for Environmental Management

Kristan Cockerill, Vincent C. Tidwell, Howard D. Passell, Leonard A. Malczynski

Environmental practitioners may find cooperative modeling an effective tool to address complex environmental management needs. The method involves convening a multidisciplinary team to collaboratively construct a system dynamics model. Advances in computational tools have made this technique increasingly effective because the process and the product allow individuals to better understand the complexity inherent in the system being studied. The authors describe four cooperative modeling projects and document some of the "lessons learned" from these experiences. Two of these projects were largely academic and team members were all professionals who agreed to work together to build a model. The other two teams were convened to contribute to water management processes. One of these emanated from a regional planning exercise and the team included professionals and volunteers from the public. The final project team presented includes professionals, members of the public, and government agency personnel. Like any multidisciplinary effort, the teams encountered communication challenges. The overarching lessons derived from these efforts are that teams can never pay too much attention to group dynamics and that the proximity to a "real" management decision does influence the cooperative modeling process. Recommendations to others embarking on a cooperative modeling effort include reviewing the literature regarding previous projects; establishing clear guidelines for team interaction early in the project; and remaining flexible, to allow the project to evolve.

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As diverse environmental concerns continue to demand our attention, professionals continue to seek tools and methods that can help address environmental management issues. One tool receiving significant attention is cooperative modeling, also referred to as collaborative, mediated, participatory, or group modeling. This technique has evolved from theories on collaboration and system dynamics.

In efforts to improve support for and implementation of positive environmental actions, agencies have embraced collaborative management ideals. A key principle of collaborative management is to shift authority from an autocratic position (agency command and control) to one of shared power among diverse stakeholder groups. The rationale is that collaborative processes can improve relationships among adversarial groups, develop problem-solving capacity, and encourage stakeholder responsibility for environmental management (Blumenthal and Jannink, 2000; Connick and Innes, 2003; Gray and Putnam, 2003; Koontz et al., 2004; Mullner, Hubert, and Wesche, 2001; Selin and Chavez, 1995; Selin, Schuett, and Carr, 2000; Stave, 2002). This shift from a single institution or a single person making decisions to a more holistic approach encompassing diverse interests is analogous to the ideas in system dynamics, which have also contributed to the cooperative modeling paradigm.

Our ideas about how to manage the environment have co-evolved with our understanding of how the physical world operates. Early environmental management approaches looked at single, target variables related to some resource and attempted to understand and manage those variables in isolation. Forest management by fire suppres-

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sion is a textbook example. The results were often unforeseen consequences and further degradation of the resource that the management approach was designed to protect (Berkes and Folke, 1998; Holling, 1995). Researchers and decision makers began to recognize that a "system is a whole that cannot be divided into independent parts or sub-groups of parts. Therefore, it has properties that derive from the interactions of its parts that none of its parts have" (Ackoff, 2001). Managing ecosystems became a more holistic way to view the physical world. This approach, however, typically excluded humans from the picture. The next step in applying a systems approach has been to link social and ecological systems in all arenas, from basic research to applied management (Berkes and Folke, 1998; Gunderson and Holling, 2002; Keough and Blahna, 2006; Lee, 1993; Newell et al., 2005; Walker et al., 2002).

Cooperative modeling is a method that utilizes principles of collaboration, as well as attempts to link the physical and the social to improve our understanding of complex systems. In this approach, a multidisciplinary team convenes to engage in dialogue, to identify key variables for a particular issue, to identify relevant data, and potentially to construct a computer model that helps team members "see" the complexity inherent in the system being studied (Rouwette, Vennix, and van Mullekom, 2002; van den Belt, 2004; Vennix, 1999). Although the model-designing process is collaborative, it is distinct from collaborative management because the team convened may or may not be charged with making any recommendations or reaching any decision. Additionally, once built, the model itself could readily be applied in any type of decision-making process, from autocratic through collaborative. The models can also be used exclusively as basic research tools and not directly linked to any specific management decision.

Cooperative modeling is also distinct from processes that employ an existing model. Computer models are ubiquitous in environmental management and possess diverse forms and labels, including integrated assessment, agent-based, back-casting, decision support system, and geographical information system. Typically, these models are pre-designed and brought to a decision-making team as tools to help them understand the issue they are addressing. In contrast, the cooperative modeling teams described here have been actively engaged in building and testing their models. In their extensive review of group modeling efforts, 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. Any model type could potentially be developed in a cooperative fashion. The most common platform used, however, is system dynamics. While Wierzbicki (2007) traces the first dynamic systems approaches back to 1931, the contemporary "father" of system dynamics is Jay Forrester, who with others developed this technique in the 1950s and 1960s. System dynamics relies on identifying causal relationships among variables and using these relationships in constructing computer models. These models allow users to ask "what-if"-type questions to see the results of various management scenarios. Forrester (1961) indicates that a model should have the following characteristics:

- Be able to describe any statement of cause-effect relationships that we may wish to include;
- Be simple in mathematical nature;
- Be closely synonymous in nomenclature to industrial, economic, and social terminology;
- Be extendable to large numbers of variables (thousands) without exceeding the practical limits of digital computers; and
- Be able to handle "continuous" interactions, in the sense that any artificial discontinuities introduced by solution-time intervals will not affect the results. It should, however, be able to generate discontinuous changes in decisions when these are needed.

He concludes that these requirements can be made operational by connecting stocks, flow rates, decision functions, and information channels, which are the building blocks of a system dynamics model. Forrester's proposal has often been metaphorically described as "bathtub dynamics." Stocks are the bathtubs themselves, decision functions are the automated or humanly controlled valves on the flows to and from bathtubs, and the information channels serve as pipes between stocks. It is also important in system dynamics modeling to be explicit about the causal relationships. A causal loop diagram is typically used to illustrate the direction of causality among variables. Figure 1 shows a simple system using dynamic modeling and causal loop icons.

There are case studies of group model building dating back to at least 1961 and the method has been used in for-profit, non-profit, and governmental sectors with increasing frequency since 1990 (Rouwette, Vennix, and van Mullekom, 2002). The model used to develop the scenarios in the book *Limits to Growth* is perhaps the best-known use of system dynamics in the environmental realm (Meadows et al., 1972). Since then, cooperative modeling has been

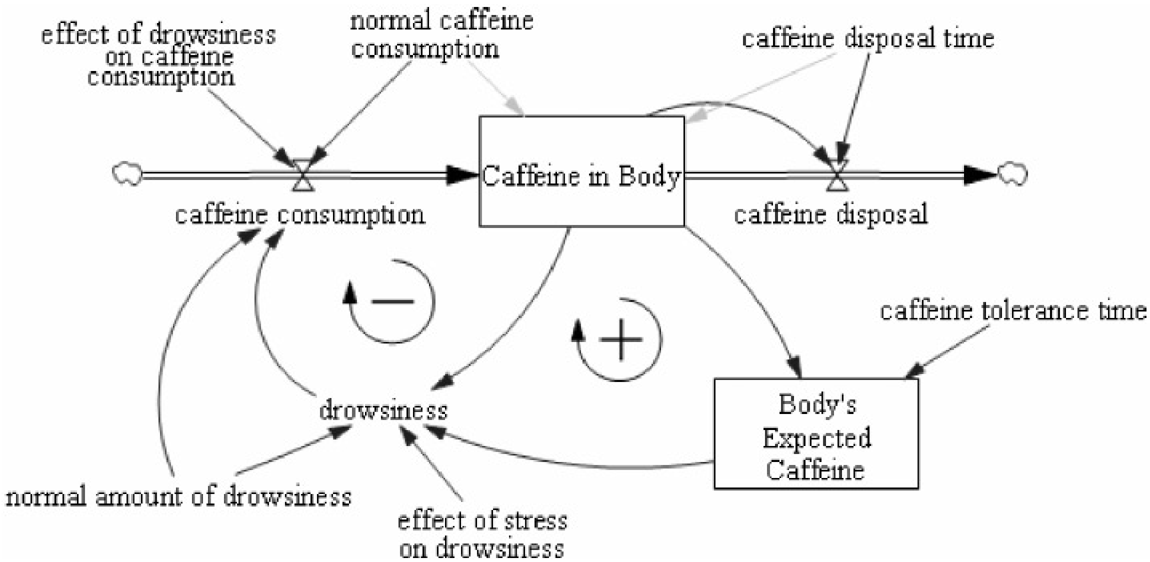

Figure 1. Using system dynamics concepts of stocks and flows and causal relationships, this diagram shows a simple "caffeine system." The "stocks" are the caffeine in the body and the body's expected caffeine. The "flows" are caffeine consumption and caffeine disposal. Balancing and reinforcing loops show the feedback mechanisms and cause-and-effect relationships. The balancing loop (–) reveals that as caffeine consumption increases, the caffeine in the body increases and therefore drowsiness decreases and caffeine consumption decreases. A reinforcing loop (+) shows that as caffeine in the body increases, the body's expected caffeine increases and therefore drowsiness increases and subsequent caffeine consumption increases.

employed on diverse environmental subjects, including assessing the effects of sheep grazing on sage grouse populations (van den Belt, 2004), energy use in iron and steel production (Costanza and Ruth, 1998), air quality issues (Stave, 2002), sustainability of Arctic communities (Nicolson et al., 2002), park management (Videira et al., 2003), and water management (Moxey and White, 1998; Tidwell et al., 2004; van Eeten, Loucks, and Roe, 2002). Cooperative modeling team composition can vary in terms of disciplines represented (e.g., biology, hydrology, anthropology) and functional roles (e.g., professional researchers, members of the public). Some team members do need to be modelers who understand system dynamics and can write the necessary code for the model. Many teams employ a facilitator and/or a notetaker. The process for cooperative modeling is flexible, to allow a team to meet the needs of its specific project. Some projects may be completed in a single meeting, while others are multi-year endeavors. The models themselves can vary from small (five variables) to quite large (1,000 variables). Traditionally, the team will meet face to face, but Web-based technology is making it possible to conduct "virtual" meetings allowing all team members to contribute from dispersed locations. Although cooperative modeling has been used for decades, its current popularity may be partially due to advances in computer technology. In addition to the ability to hold "virtual" meetings, the software available for constructing system dynamic models makes it relatively simple for modelers to build a model and also relatively simple for novices to run one. Additionally, improvements in computer interface functions make model output more accessible to non-technical users.

There are numerous rationales posited to support using a cooperative modeling approach. Vennix (1999) reports that because human brains are not very efficient information processors and do not readily think in terms of causal relationships or feedback loops, cooperative modeling can be particularly helpful in dealing with "messy problems" that have complex system characteristics. Building a model allows participants to begin to appreciate the complexity, and the team therefore develops a common understanding of the issue, which improves the odds that results from the collaborative effort will be implemented in cases where the model is used in decision making (Palmer, Keyes, and Fisher, 1993; Rouwette, Vennix, and van Mullekom, 2002; van den Belt, 2004; Vennix, 1996). By constructing a model together, participants can better appreciate the difficulties in capturing the relevant variables and securing accurate data so that participants come to be vested in the tool and hence support its output. Case studies of cooperative modeling for a variety of subjects show that the technique increases knowledge levels about the particular topic, as well as increasing levels of consensus about a problem and mitigating approaches (Costanza and Ruth, 1998; Rouwette, Vennix, and van Mullekom, 2002; van den Belt, 2004). This technique can also utilize the benefits of synergy by enabling the group to develop new policy options in deadlocked processes (van Eeten, Loucks, and Roe, 2002).

It is important to note, however, as Rouwette, Vennix, and van Mullekom (2002) do, that the literature does not well reflect efforts that failed to reach their goals or suffered from poor group dynamics or miscommunication. Therefore, it is difficult to ascertain how widespread attempts at cooperative modeling have been. This article contributes to the knowledge base by describing several cooperative modeling projects that provided the authors with a diverse array of lessons. The experiences reported here have provided insight into how to "do" cooperative modeling. Some of the lessons learned are not necessarily insightful to anyone who has attempted projects such as those described here, but because the approach is still evolving, everyone is still on a steep learning curve and all lessons are valuable. Additionally, because these efforts are multidisciplinary, the existing literature is less than cohesive; ecologists publish their experiences in the ecology journals, modelers publish in the modeling literature, and economists write for the economic publications. Further, the existing literature has paid less attention to the group dynamics of the cooperative modeling process than to the resultant models, their output, and their use (notable exceptions are Moxey and White, 1998, and Nicolson et al., 2002). Our experiences confirm that, like any participatory effort, key variables affecting group dynamics—and hence the cooperative modeling process—include a project's objective, as well as group characteristics.

Cooperative Modeling Projects

Since 2002, the authors have worked together on several projects utilizing a system dynamics platform to cooperatively develop computer models related to water and land use management issues. The methodology employed has been to establish a multidisciplinary team that agrees to work together to build a model incorporating expertise from their respective disciplines. This article describes four projects, in order to demonstrate various experiences with the cooperative modeling concept. The efforts reported here reflect two broad categories: those that are connected with a specific management effort and those that are not. The latter are technical efforts designed to explore ways to advance the system dynamics approach and the cooperative modeling method; the two projects in this category feature teams comprised of professionals ("experts") from diverse disciplines. The other two teams were convened to contribute to resource management decisions; a public volunteer group that worked with professionals drove one of these, and the second project team includes professionals, members of the public, and public agency managers, as well. Figure 2 provides an overview of the characteristics of these four projects.

Professional-Only Teams

Toolbox Project

In 2003, the authors began work on the Toolbox Project, a three-year cooperative modeling effort focused on developing discrete system dynamics "process modules" that are "swappable," thereby enabling others to more rapidly build a model to address their specific water management needs. A team of more than 25 professionals from federal agencies, state universities, and consulting firms representing ecology, economics, law, geography, policy, hydrology, and chemistry contributed to the model. Team members were geographically dispersed throughout Arizona and New Mexico. There was not a facilitator for this project. The principal investigator ran the meetings and the lead author took notes to document team decisions about data, model structure, and work assignments.

This project changed its geographic scope and focus more than once. The initial focus was to assess water banking in the Middle Rio Grande region of New Mexico. Water banks allow water rights holders to "bank" their rights so that others can temporarily "borrow" them. This can be a valuable drought mitigation tool. Early in the project, several team members requested that the project shift its geographic focus to the more southern reaches of the river, which the principal investigator agreed to do. Pending lawsuits in that region, however, precluded obtaining the data necessary to validate the model against the historical record, so the geographic scope returned to the Middle Rio Grande. Additionally, in the second year of the project, a subset of the team determined that the water banking aspect should be a sub-project, rather than the primary focus. Therefore, the team shifted its focus to building a model allowing users to assess water flow in a region and identify tradeoffs among water uses—residential, industrial, commercial, and institutional.

	Resource Management *(Connection to management decisions)*	**Academic** *(No connection to management decisions)*
	Middle Rio Grande Project	**Toolbox Project**
Composition	Professionals, public	Professionals
Size	6-15	25
Team dispersion	Low	High
Duration	2.5 years	3 years
Meeting frequency	1-2/month	2/year
Topic	Narrow	Broad
Focus	Static	Several revisions
Geographic focus	Static	Several revisions

	Southwest Modeling Project	**Land Use and Water Transfers Project**
Composition	Professionals, public, policy makers	Professionals
Size	20	12
Team dispersion	High	Low
Duration	1+ year	1 year
Meeting frequency	2-3/month	1/month
Topic	Narrow	Narrow
Focus	Static	One revision
Geographic focus	Static	Static

Figure 2. Characteristics of the collaborative modeling projects and teams described.

This team was not cohesive, owing in part to its size, the diversity of organizations and departments represented, and the infrequent group interaction. Additionally, there was some tension surrounding the foci changes, because decisions were not made within the team as a whole, but between the principal investigator and a sub-group. There were about eight scheduled meetings for the entire team. Because the team was dispersed, not everyone could attend each meeting and therefore the various disciplines did not interact with each other on a regular basis. Discipline-specific sub-groups met more often and developed modules that the modelers then integrated.

Because of this segregated approach, the group did not develop cross-disciplinary communication skills and there were issues with finding common language. For example, late in the project, in trying to determine if data were available to demonstrate relationships among particular variables, the principal investigator reached an impasse with the economists, who contended that it was not possible to show "tradeoffs" among the variables being considered. After several discussions about options, one of the economists asked the principal investigator to define "tradeoff." From the principal investigator's perspective, a tradeoff simply showed a difference between one alternative and another. To the economists, a tradeoff was a very specific term to reflect marginal value. With the broader definition in place, they were able to agree that the existing data were sufficient to show tradeoffs.

Other communication problems developed because some team members did not invest the time to thoroughly understand the modeling technique being used and the infrequent interaction meant limited exposure to the technique. Reflecting this, the project was into its second year when some team members realized that they were not appropriately interpreting causal loop diagrams, a fundamental component of system dynamics. This lack of understanding had contributed to long discussions in meetings, where it is now apparent that individuals were "speaking past each other" because they were employing different interpretations.

The project was successful in developing a system dynamics toolbox to support water resource planning (Tidwell et al., 2006). Associated modules address diverse issues, including surface and groundwater hydrology, climate, water quality, irrigation, residential/industrial water use, aquatic and riparian vitality, economic growth, and demographics. To test the toolbox, these disparate modules were assembled into a working model of the Middle Rio Grande, with the subsequent output compared to historical data. Additionally, a separate water banking model was developed for the same region and used in an experimental setting (Brookshire et al., 2006). Although successful in its overarching goals, the project and resulting toolbox would have benefited from greater interdisciplinary interaction, particularly in the coupling and interfacing of physical and social processes.

Land Use and Water Transfers Project

Another professional-only team gathered in 2004 to study land use pattern change, particularly the shift of irrigated land to municipal uses, in the Middle Rio Grande region of New Mexico. Although there have been obvious changes in the landscape in the past 50 years, the specific mechanisms and drivers for this change are understudied. Because all land uses require water, the principal investigator hypothesized that modeling water rights sales and the subsequent effects from those sales would lend insight into the changing landscape. In the western US, water is regulated on a priority basis and entities who first put water to beneficial use have the first "right" to that water. In New Mexico, water is considered a property right that can be bought and sold. To use water, there must be a legal right associated with that water.

This team included 12 individuals with expertise in ecology, economics, anthropology, policy, law, agriculture, and hydrology. Participants were all from central New Mexico and represented a federal agency, a state university, and private consultants who worked together for one year, meeting about once a month. This team did not include any formal facilitation, although when necessary, the principal investigator took on that role. A team member did take notes in anticipation of preparing a final report. Although there were some early struggles in trying to understand research methodologies emanating from the diverse disciplines, the team became quite cohesive and effectively moved between small discipline-based or topic-based sub-groups back into the unified group to integrate data and ideas. Team members seemed to genuinely enjoy working together and, in fact, socialized outside the project. This level of rapport no doubt contributed to positive cross-disciplinary communication. Additionally, most of the team members had participated in other modeling projects and understood system dynamics principles. Team members were already familiar, or rapidly became familiar, with each other's terminology and avoided miscommunication due to multiple definitions of key words that we experienced in the Toolbox Project. One reason contributing to good communication was that the project was fairly narrowly designed from the outset; the Middle Rio Grande was the geographic area and assessing causes for land use change remained the focus. Also contributing to the team's success was that, early in the project, team members prepared narratives to explain the systems relevant to the project and these were used to draw preliminary diagrams showing causal relationships among variables. This further established the bounds of the project and highlighted how the various disciplines might contribute to the effort.

The team initially tried to document water rights sales/transfers in order to map that data onto land use change. About halfway through the year, the project team had to revise its approach, because it became clear that the water transfer data were unreliable. Additionally, visits to farms and interviews with farmers (who have historically been the largest land holders in the region) revealed that water was not a decision driver among those who might be tempted to sell their land and/or change its use. The team therefore turned its attention to other drivers, including increasing property taxes and urban encroachment, as greater drivers to predict land use changes. This finding highlighted the need to be intimately familiar with the physical processes being modeled, as well as with the "local knowledge" about the system. Specifically, those with "local knowledge" need to be involved in the initial stages of conceptualizing a project and the potential model structure.

Because of the lack of data and the late focus change from water rights sales to other factors, the resulting model is fairly simplistic and is based largely on team member insight and hypotheses rather than on numeric data. The process, however, uncovered very interesting findings regarding the status of data and landowner behavior in the region, as well as provided lessons about applying methodologies from various disciplines. The team considered this effort a success, because it did highlight issues in collaborating across disciplinary cultures and provided insight into integrating social data into a system dynamics project. For example, the social scientists on the team encouraged stakeholder interviews earlier in the process and if that had occurred, the key question may have been revised earlier and changed the overall effort. Additionally, team members believed that with a longer project time frame, alternative data for the revised focus could have been gathered and used to strengthen the model. Further details on this project can be found in McNamara et al., 2004.

Professional and Public Team

Middle Rio Grande Project

In 2002, the second and third authors engaged a volunteer group that was spearheading a regional water planning effort, proposing that they cooperatively develop a model that would show the relationships among various water management and conservation strategies for the Middle Rio Grande region in New Mexico (Tidwell et al., 2004). This is one of 16 planning regions that the New Mexico Interstate Stream Commission (ISC), which has responsibility for water management in the state, tasked with developing water management plans documenting supply and demand.

The Middle Rio Grande Project team began its work with about 15 members, which dwindled to about six over the two and half years of the project. The non-modeler team members were volunteers from the region who had expertise in geohydrology, ecology, agriculture, economic development, and law. For the first year, the team met twice a month and then reduced this to about once a month. This group had a dedicated facilitator who also took notes during meetings. The project's focus and its geographic range were well established at the outset and remained constant throughout the effort.

The initial group lost cohesiveness, in part due to public participation pitfalls including a loss of trust, concerns with data, concerns with political agendas, and the long duration of the project. Although participants did consider it successful, the project suffered from a lack of attention to basic public participation guidelines, such as clearly defining goals and expectations. There were also difficulties with communicating across the "expert" to "layman" disciplinary boundary, specifically related to decisions about what data to include in the model. For example, one team member repeatedly cited a data point but never supplied an actual source for the data; hence the modelers did not include it in the model and this was perceived by some to be a bias. The modelers also made some communication mistakes by holding meetings with agency officials not involved in the model development project. Several team members interpreted this as capitulating to political pressures regarding model content and output. For a more detailed description of the group dynamics in this project, see Cockerill, Passell, and Tidwell, 2006.

Despite these negatives, the smaller group that participated throughout the entire process did develop cross-disciplinary communication skills. Interviews with team members indicated that one cohesion-generating event was a "field trip" the team took to learn about the systems being modeled. This, coupled with a generally positive and cooperative attitude among participants, enabled the group to produce an accurate, comprehensive model with more than 900 variables. This model has been demonstrated in diverse venues (e.g., public meetings, school groups, professional meetings), where users can compare various water management alternatives and see the effects on aquifer drawdown, river flow levels, and monetary costs. Although the model was a key tool in facilitating the planning process, actual numbers from model output are not the basis for the plan's recommendations. One reason for this is the continued lack of consensus among the modeling team, the broad planning group, and relevant institutions as to the neutrality of the model, the validity of its assumptions, and the accuracy of various data sources. In post-project interviews, however, team members agreed that developing the regional water plan would have been more difficult without the model.

Once the plan was complete, the Middle Rio Grande team began work to put the model on the Web so that it could be used even more widely in ongoing water management discussions. Unfortunately, because the team did not clearly define roles when the project began, a debate about model ownership has resulted in a complete breakdown of communication between the team's public and federal agency members. The model, however, is available on the Web at http://nmh2o.sandia.gov/ExTrainSD.

Professional, Public, and Manager Team

Southwest Modeling Project

Following a 2004 federal settlement that granted additional water rights and funding to the southwest region of New Mexico, Interstate Stream Commission personnel agreed that a cooperative modeling project could positively contribute to the decision-making process. The collaborative process and the model will allow users to ask "what-if" questions concerning various options for allocating the "new" water and the affiliated money. This modeling focuses on the surface and groundwater resources of the Gila and San Francisco Basins in New Mexico. The Mimbres and Animas Basins are also considered, due to the potential for interbasin transfers from the Gila, as are flows in the Gila and San Francisco Rivers downstream in Arizona, which influence when and how much water could potentially be diverted in New Mexico. Primary demands on these water resources include irrigation, mining, livestock, limited industrial withdrawals, and residential/domestic uses. The presence of endangered species plus the fact that the Gila and San Francisco Rivers are free flowing make environmental concerns very important in this area. There are no existing surface or groundwater management models available for this region; thus, all modeling is starting from scratch.

Since it was established in September 2005, the cooperative modeling team has included approximately 20 representatives from several federal agencies, state agencies, county government, municipal government, county soil and water conservation districts, environmental interest groups, and the mining industry. Professional and public expertise includes hydrology, economics, ecology, policy, agriculture, ranching, and development. This team is employing a facilitator and a notetaker. There is also a publicly accessible Web site, where meeting notes and other information are posted (http://waterportal.sandia.gov). We have had significant turnover among federal agency participants. For example, five different employees from one federal agency have served on the team. To date, this has not been an issue, as new members have been educated on the project.

The original project timeframe was one year, but as of this writing, the model is still in draft form and the team will continue meeting into spring 2007. One unique characteristic of this project is that the majority of the meetings are conducted via Webex, Internet technology that allows numerous computers to be linked so that everyone participating sees and can use the same computer screen. During the meetings, team members speak via a conference call. Although there have been a few technical glitches, the system has worked quite well and allows this geographically dispersed team to meet every two weeks. Participation has waned a bit, but remains quite strong and there have been few negative communication issues. Contributing to this success is the fact that many of the modeling team members are also members of a regional water planning group that has been meeting regularly for several years. Previous interaction has enabled them to become familiar with each other and to recognize common definitions of terms and concepts. Additionally, many of the participants are extremely familiar with the physical systems being modeled. They live and play in the river basins being studied and can provide first-hand knowledge about the dynamics in these systems.

One of the lessons learned so far in this effort is that individuals did not immediately understand that the team, as a cohesive unit, will make decisions about what to include in the model, what data to use, and what alternatives to explore. Early in the project, there seemed to be a perception that the modelers had a model designed that they were simply revealing to the team for comment. The lead author and the project's notetaker conducted individual interviews with each team member, precisely to better understand group dynamics like this. These interviews revealed that individuals hold false assumptions about what outcomes other team members desire for the settlement. So, despite the previous relationships among various team members, there is still some level of mistrust and potential misunderstanding about this particular water management issue. Despite this, there has been fairly strong team cohesion and commitment to the process. An exception was that one member resigned because this is not a decision-making effort and this person believed that it was best to wait and invest time in a process that would directly result in a decision. A survey of team members about 10 months into the project revealed satisfaction with the process and optimism that the model will be helpful in the state's decision making. A few months later, however, another member resigned over concerns that environmental interests are dominating the process.

Discussion

Although there are an increasing number of cooperative modeling projects being initiated, the groups or agencies conducting them may or may not be well versed in the literature related to collaboration, group communication, and public participation. This is a challenge in any multidisciplinary work. What is considered basic knowledge in one discipline is entirely novel to another. In some of the literature cited in this article, authors report "lessons learned" that may seem naïve to professionals within communication-based disciplines, yet are new to professionals from other disciplines. The Middle Rio Grande Project is a classic case of this. Although the team had good intentions and was convened in an open and participatory way, there were communication issues that could have potentially been avoided. At the same time, perhaps the primary lesson we have learned is that it is difficult to tease out exactly what contributed to the specific experiences of a particular group and it is difficult to predict when or where communication issues will arise. Nicolson et al. (2002) use the term "heuristics" in their title, while Moxey and White (1998) discuss "reflections" related to cooperative modeling efforts. They use these terms rather than "rules" or "guidelines" to emphasize the fluid nature of this method. Each modeling project is unique and the dynamics generated cannot possibly be predicted at the outset, and hence they require flexibility rather than rigid rules. Therefore, it remains a valuable exercise for each team to report its experiences, positive and negative, informed and uninformed, so that the body of knowledge continues to grow.

In this accord, we have two overarching and connected lessons that we will take with us to future projects. The first is that because each team is unique, there will likely be some communication issues and teams need to be diligent about watching for signs of negative group dynamics and/or miscommunication. Group dynamics are influenced by group composition (e.g., professionals, public), size, geographic dispersion, and existing familiarity among members. The second overarching lesson is that a project's proximity to a "real" management decision affects group dynamics and hence the entire process. This emphasis on group dynamics and the process is key, because although these are collaborative modeling projects, the model may not be the most important outcome. The cooperative structure means that teams can gain significant insight into an issue without relying on model output. As noted in describing the Land Use and Water Transfers Project, the team discovered important data gaps and identified key variables relevant to land use change, independent of the model created. They also successfully explored how to integrate social data into a system dynamics model. In the Middle Rio Grande Project, team members reported that the process of developing the model was tremendously helpful in getting the planning team into a position to write a plan. The model's numeric output, however, was not the primary source for the plan's final recommendations. This is not unexpected in system dynamics modeling, because the process is as important as the product (Ford, 1999). As Sterman (2000) describes, a typical attempt to model a problem using the system dynamics approach starts with listing variables of interest, creating reference modes or time graphs, building causal loop diagrams, developing dynamic hypotheses, and then, *if required*, building a computer model.

Group Dynamics and Communication

Key to establishing a productive process is learning to communicate among the diverse disciplines and interests that are represented on a cooperative modeling team. Communicating across disciplinary lines is always challenging. Each discipline comes to the table with their own vocabulary, theories, methodologies, and tools (Moxey and White, 1998; Nicolson et al., 2002; Snow, 1959; Wear, 1999). Cooperative modeling ideally attempts to transcend disciplinary bounds and to find a place where all of the disciplines can mix into something new and truly interdisciplinary (Klein, 1990; Policansky, 1999). Multidisciplinary communication challenges are exacerbated in cooperative modeling, because not only must individuals learn new vocabulary and concepts from other disciplines, but everyone must also learn about general principles of system dynamics modeling. Our experiences reflect findings in other cooperative modeling work (Moxey and White, 1998, and Nicolson et al., 2002) that it is important to clearly define the project at the outset. This should include communicating what system dynamics models are designed to do and what they are not capable of doing, as well as discussing how data should be gathered, interpreted, and used in the effort. Our experience indicates that any type of team (professional, public) can benefit from having a facilitator and a notetaker. The facilitator can be a communication guardian, watching for potential miscommunication and for language barriers across disciplines. Having a solid set of notes that document both content and group dynamic information can help highlight potential recurring communication issues, which can then be resolved before they become problematic. If we had employed an independent facilitator and/or maintained more comprehensive notes in the Toolbox Project, it may have become obvious earlier that team members were not accurately reading the causal loop diagrams. Notes can also help a team maintain focus, because previous discussions can be reviewed, rather than repeated.

One benefit to working with a professional-only team is that although research methods and standards differ among disciplines, participants are familiar with general research principles and have likely employed models of one kind or another. Another benefit is that professionals can more readily commit the time and energy required for a cooperative effort. There is no guarantee, however, that team members will offer this commitment, as the authors learned in the Toolbox Project.

The time and resource intensity of cooperative modeling efforts is problematic for teams that include the public. Because team members are likely to be volunteers, it can be difficult to obtain the level of commitment required for long-term projects such as those discussed here. Additionally, the public participants may come to the process with little or no experience in conducting research, with little or no background in the issue to be addressed, and with numerous misconceptions about the issue. Some members may want to participate simply to pursue their personal agenda rather than truly investing the time to create interdisciplinary results. Conversely, public participants can contribute local knowledge to a project that professional-only teams would miss. We have consistently seen this in the Southwest Modeling Project. Team members have provided suggestions for several dozen data sources relevant to this work. As already noted, many of the team members are intimately familiar with the region being studied and are able to clarify the relationships that form the basis of the model's structure. When organizing cooperative modeling teams, it is important to identify what interests and knowledge sets will best contribute to the project. This poses a challenge in terms of trying to balance team size with obtaining comprehensive coverage of the system. For projects that incorporate the public, one option is to establish a core team that well represents the broad interests relevant to the system under study and to then "outreach" to others who may have pertinent data or who may want to review drafts of the model at various stages, but who are not interested in participating as full team members. Creating a process like this requires that the "rules of engagement" be clearly established very early in the project.

Experience with the Middle Rio Grande Project revealed that it is important to establish ground rules for how the team will interact and make decisions. For example, how will decisions be made (e.g., simple majority vote, unanimity) and what roles will team members play? What level of commitment can team members give? Teams should explicitly discuss how to balance team control with efficiency in completing the project. For example, will the team members be responsible for identifying and gathering data to give to the modelers? Or will the modelers find the data and generate draft models for team review and comment? Is it permissible for the modelers to meet independently with potential sources and agencies not involved in the project? These kinds of questions should be addressed at the outset to avoid miscommunication in a public-focused effort. The Southwest Modeling Project did establish ground rules very early in the effort and we have used them to resolve questions regarding team membership and disseminating information to the broader public. Figure 3 represents the spectrum of possibilities for team-controlled versus modeler-controlled processes. The more work the team adopts, the more transparent the process and the model will be. Each team must weigh the time and energy requirements against the level of trans-

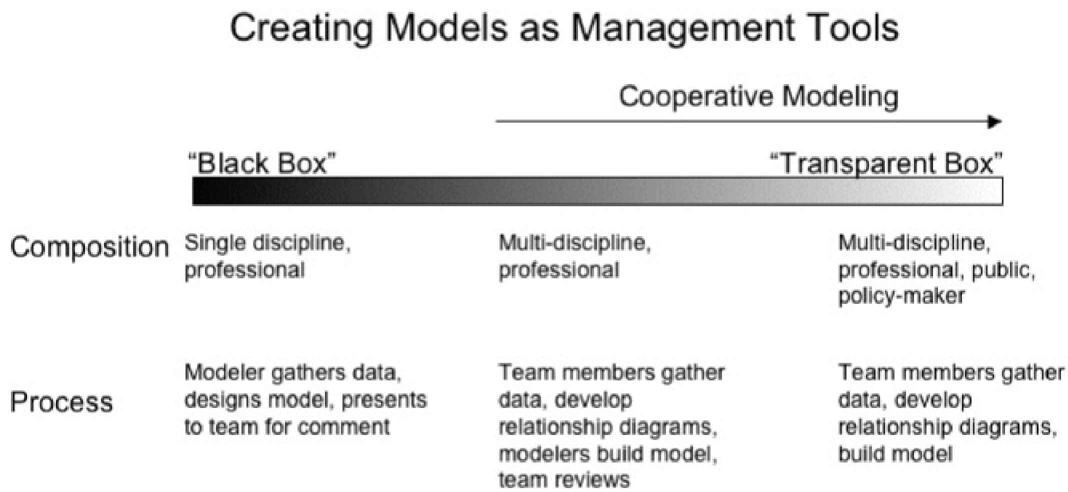

Figure 3. Cooperative modeling helps teams move toward transparent processes and transparent models. The more disciplines and/or interests involved and the more of the workload that the team adopts relative to the modeler, the more transparent the project will be.

parency desired and agree on the workload of team members *vis a vis* the modelers.

Both of our projects involving the public focused on contentious management issues. In these situations, the level of familiarity among group members seemed to contribute to success. If team members have already established positive (or at least neutral) relationships with each other, this can ease communication within the modeling project and make the process more efficient, because time can be spent discussing data and causal relationships rather than focusing on team building exercises. As Wondolleck, Gray, and Bryan (2003) discuss, collaborative efforts often start from an "us versus them" position, but as participants get to know each other, some of the extreme identity labels (e.g., "radical environmentalist") begin to fade. In the Middle Rio Grande Project and the Southwest Modeling Project, several team members knew each other prior to joining the cooperative modeling effort and this likely contributed to the mostly positive group dynamics during model development. This is not to suggest that these teams experienced zero conflict. But because team members had, to some extent, moved beyond intractable "us versus them" positions, the modeling teams were able to be effective.

Team size and geographic dispersal contributed to the group dynamics in all four projects summarized here. Personal interaction is important in encouraging cross-disciplinary communication and developing a solid rapport among team members. The Land Use and Water Transfers and Middle Rio Grande Projects were not geographically dispersed and were also relatively small. Convening meetings was still a challenge due to busy schedules, but early in each project the principal investigators emphasized the need to meet regularly and team members were committed to the projects. In both cases, despite the differences in the robustness of the final models, both sets of team members declared their model building projects successful. For the Toolbox Project, meeting frequently as a whole group was not feasible because of the group's large size and dispersed nature. This resulted in minimal group communication, and responsibility for integrating across disciplines fell to the principal investigator. In framing the Southwest Modeling Project, we wanted to utilize the lessons from our previous experience. We knew this would be a large team that was geographically dispersed, and therefore, frequent (e.g., at least monthly) face-to-face meetings were not feasible. The principal investigator suggested we use Internet technology that allows the team to meet "virtually" every two weeks. So far, this has enabled a level of cross-disciplinary cohesiveness that the smaller, less geographically dispersed groups experienced. Although comments on the mid-project surveys indicated that Webex was working well, team members also noted that face-to-face meetings were more productive and enhanced positive group dynamics. The team therefore, agreed to quarterly in-person meetings. Analyzing how and when teams might best use computer linking software is an area that warrants further research.

Proximity to Management Decision

Comparing the projects that were largely academic with those more directly connected to a pending decision did reveal some differences. Unique among documented cooperative modeling efforts, both the Toolbox Project and Land Use and Water Transfers Project described here were done "in-house," meaning there was not a client who requested the work and they were not directly tied to a specific or pending management decision. Therefore, the teams could experiment and had the freedom to try diverse approaches. This is a positive situation when trying to truly understand a complex system and to identify new approaches to modeling those systems. As conditions change, knowledge grows, and the team can respond without violating an obligation or agreement with a client. This flexibility provided excellent learning opportunities, as both of the professional-only projects did change direction when the teams learned more about their topics. The ability to change foci is perhaps more appropriate in the professional-only efforts, whereas in public projects, shifting foci may lead to greater controversy if the shifts are not well explained or are perceived to be the result of some bias. Additionally, in the professional-only teams, there was a greater sense of freedom for team members to openly propose any and all ideas without fear of being perceived as pushing an agenda. There was also no concern about what the model might reveal, because the projects were more "academic" than "real," and model results were intended to elucidate.

Although the Toolbox and Land Use and Water Transfers Projects were not intended to contribute directly to management decisions, an important aim of the cooperative modeling approach is to assist the public and managers in making better decisions. Therefore, a negative aspect of not having a client is that there is a strong likelihood that the work will never be used in any management arena and will become "shelfware." One reason for this is simple ignorance. If policy makers do not know that a model exists, they are not going to employ it. While professional-only projects can be invaluable in developing the experiential and technological infrastructure to be applied to future management projects (as is the case for the Toolbox Project, where resulting modules are being used in the Southwest Modeling Project), the project team needs to ensure that others know what they have done, if they want to see their work eventually applied.

Another rationale for decision makers not to employ a professional developed model is intentional ignorance. When modeling projects address complex and controversial issues, the authors have encountered attitudes among some decision makers that it is better for them not to know about the project's lessons and/or the model's output, so that they do not need to address the issue or can maintain the status quo. Stave (2002) reports that a client may want just enough information to solve the problem, but not to actually understand the system or to challenge any basic beliefs. If a model's output does challenge basic beliefs, it is likely to be disregarded.

There is also the possibility of "dueling models." If policy makers already have a tool, and output from the cooperative team's model disagrees with the decision maker's model, this can create conflict and decision makers are likely to support the model with which they feel the most ownership. This may be especially true if the models differ in their purpose. A predictive model may give output that suggests certainty, while system dynamics models are not about making point predictions, but are designed to help builders and users better understand patterns (Ford, 1999). This is another benefit of the system dynamics approach, but it may only be effective if decision makers are active participants in the model development process. For this reason, agency personnel who would likely be involved in the eventual decision were asked to participate in the Southwest Modeling Project.

Unlike the professional-only efforts, team members in the Middle Rio Grande and the Southwest Modeling Projects were/are definitely concerned about the models' outputs and a sense of the "realness" of the stakes in developing a tool to be used in a decision-making process. As Figure 3 shows, cooperative modeling helps to move model development from a "black box" toward a "transparent box," where team members can see exactly what goes into the model and hence what drives the outcome. If members of the public and managers who represent key interests are at the table when the model is developed and have a say in establishing parameters, delineating assumptions, and determining what data to use, they then have a vested interest in the model's output and are less likely to criticize the results. They are, therefore, also more likely to support using the model in management decisions. Cooperative modeling can help segregate value issues from factual details about how a system works (Lorie and Cardwell, 2006). This can help change how people view an issue. As Forrester (1993) notes, "System dynamics models have little impact unless they change the way people perceive a situation. A model must help to organize information in a more understandable way" (p. 219).

Ideally, this more holistic approach can alleviate the "dueling model" problem, because the decision makers are familiar with the cooperatively generated model and can assess its relationship to other models used in reaching a decision. When managers are involved, it may be appropriate for them to delineate how they see the model development process and/or the model itself being used in making a particular decision. Decision makers can contribute to the discussion by explicating political barriers and/or identifying data sources that are not available. It is important to recognize Sterman's (2000) ideas, however, that teams should not limit themselves with assumptions about what is politically palatable. It is more interesting and potentially more effective to pursue all possible options and see what the causal loops and model reveal.

Conclusion

Our experiences with cooperative modeling suggest that it is an effective approach for any group that wants to better understand a system. It can be a valuable tool in both educational and decision-making settings. Because this is still a relatively new approach, teams should be encouraged to report their lessons, both positive and negative, so that others might continue to learn how to best employ cooperative modeling as an environmental management tool. The projects described here offer insight into some of the advantages and disadvantages of various types of cooperative efforts. Although previous lessons are helpful, they do not protect a cooperative team from making mistakes and do not ensure a successful venture. Still, we offer the following summarized list of considerations drawn from our projects and the discussion presented in this article.

Lessons Learned Summarized

- Each cooperative modeling project is unique and therefore each group will face unique challenges that require attention.
- Teams should familiarize themselves with existing literature to benefit from the lessons that others have learned.
- Employing a facilitator and notetaker can ease and/or avoid some communication pitfalls. The facilitator should possess expertise in the field of interest, as well as in facilitating ongoing group dialogues.
- Teams should meet frequently to better ensure their ability to communicate across disciplinary boundaries, as well as to become familiar with the modeling techniques being employed. For geographically dispersed teams, "virtual" meetings offer a mechanism to achieve this.
- Establish ground rules and expectations at the beginning of any project. These should cover how the team will interact, how they will make decisions, who will "own" any final products, and whether and how these are to be disseminated.
- To the extent possible, ensure that teams include a healthy mix of members with local knowledge of the system and members with modeling and/or subject expertise. To encourage diffusion of knowledge between team members, it may be beneficial to take field trips to view system features that are to be included in the modeling effort. This not only will assist the team in more clearly understanding the system, but the shared experience can help improve dialogue and rapport among team members.
- Last, teams should remain flexible enough throughout the process to take advantage of new knowledge or approaches.

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