Water Resource System Modeling for Conflict Resolution

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Introduction

"... resolution of conflicting goals is a uniquely human function, imperfect and irrational as it may be. No optimization method - indeed, no model - can tell any decision-maker how to evaluate the degree to which various individual (or common group) desires should be fulfilled or compromised." Jon Liebman (1976)

Throughout most of the industrialized world, water reservoir systems are largely developed; relatively little new reservoir development can be expected. The application of reservoir operations and planning models has shifted from the development of water resources on a *tabula rasa* to the improved operation of a largely existing reservoir infrastructure for ever-evolving system operating objectives. The operation of existing systems in a partly water-dependent economy for new socially-desired objectives (such as most environmental objectives) entails conflict. These conflicts include those between the early economic purposes of water development (flood control, agricultural and urban water supply, hydropower, and navigation), newer economic and social purposes (such as recreation and waste assimilation), and recent environmental objectives (such as endangered species).

Over the last decade, almost every major system has entered a period of conflict over its operation. Examples include: the Missouri River system, with its necessary tradeoffs between navigation downstream and hydropower and recreation upstream, the Columbia River system, with its conflicts between fish migration flows and hydropower, the Appalachicola-Chattahoochee-Flint (ACF) system with its conflicts between upstream urban water supply, downstream estuarine environment, and middle-reach navigation, and California's never-ending conflicts between agricultural, environmental, and urban water demands, broadened recently to explicitly include flood control. These conflicts take place within developed economic and political systems, with vested interests in the operation of each water system plus a context of economically or politically inter-twined non-water issues.

How can water resource system models contribute to resolving these complex and difficult problems? Or can such models help at all? The implicit assumption that models inherently reduce conflict, a frequent view in the 1960's, is called into question. This paper seeks to organize some ideas on the subject and ventures some hypotheses regarding potential answers. This organization of the problem and hypothetical answers stem from the authors' experiences with real systems and some of the larger literature on systems engineering and political science.

Roles of Modeling in Conflict Resolution Problems

Computer models do not resolve conflicts; people do. However, computer modeling can serve several roles in helping people resolve water resources conflicts. Many of these are classical contributions of computer models to problem-solving in general.

1. Further understanding of the problem. Computer models of water resource systems require a clear and consistent conceptualization of the workings of these systems. Without computer models, there is often little attempt to formalize or systematize an understanding of how these systems function (Lord, et al. 1990). As a rather dim student, the computer must be told every step of how a system works. This insistence on a clear and consistent understanding of the system is a prerequisite for good technical solutions to a problem. Even where the understanding represented in a model may be oversimplified or even wrong, the model's representation becomes a starting-point for improving a systematic scientific understanding of the problem (Holling 1978).

2. Formalizing performance objectives. Another aspect
of understanding a problem furthered by computer modeling, especially relevant for conflict resolution, is the required formalization of performance measures. For models to be useful, their output must be expressed in forms that have meaning in terms of the performance objectives of different parties. This requires that the different parties propose quantitative measures of system performance for the operating objectives they espouse. Without the requirements of computer modeling, it is often difficult to motivate parties to precisely describe their definition of "desirable" performance and how different trade-offs in performance might or might not be important.

3. Developing promising alternatives. Computer models are close to ideal "experimental worlds" for developing innovative alternatives for solving problems and resolving conflicts (Holling 1978). Using a computer model, a wide range of alternatives, and especially innovative alternatives, can be tried, developed, and refined at relatively little cost and in a relatively short time compared with experimenting in the "real" world. Having a wider variety of alternatives and an ability to quickly develop new and hybrid alternatives makes it more likely that an alternative can be found that comes closer to satisfying the desires of stakeholders involved in water resources conflicts, and thus facilitate compromise and negotiations.

4. Evaluation of alternatives. Computer models provide a very rapid and standardized means of evaluating alternatives in terms of the multiple criteria likely to concern conflicting stakeholders. Computer models allow hundreds, or even thousands of alternatives to be evaluated in a standardized and reproducible way with the time and resources traditionally required to perform a single analysis manually. The rapidity, standardization, and relative completeness of such evaluations also can facilitate negotiations and compromise.

5. Providing confidence in solutions. A final and perhaps overarching role for modeling in the resolution of conflicts is to provide greater confidence for decision makers that proposed solutions will function as intended, and that actual trade-offs will correspond somewhat to those understood by decision makers based on model results (Gass 1984; Loucks 1990). Good modeling studies should also provide confidence that a wide range of alternatives have been examined, so that the recommended solutions are likely to be among the best. In the end, engineers and planners use models because we think they lead to better and better-understood solutions.

6. A forum for negotiations. Some recent efforts have been made to employ model development and use as a forum for negotiations and conflict resolution (Sheer, et al. 1989; Thiessen and Loucks 1989; Keyes and Palmer 1993, 1995; Palmer and Keyes 1993). The intent often is to employ the logic of modeling studies and development to structure the negotiations process, using the model as a forum for negotiations. Beyond lending structure to a negotiations process, models can contribute to negotiations through their classical roles, as outlined above. This may take the form of rapid prototyping and evaluation to aid negotiations, or through the use of simulation gaming to help interests explore the system and develop and test options on their own. There is some evidence that computer models can be helpful in negotiation settings (Reitsma, et al. 1996).

Classical Multiple Objective Analysis

Classical multi-objective analysis has often been proposed for helping to study and resolve conflicts. These forms of analysis generally fall into two categories (Cohon 1978), methods which generate noninferior (Pareto-optimal) solution sets and those which incorporate multi-objective trade-off preferences to select a best alternative. Methods for generating noninferior solution sets are intended to inform decision-makers of the performance trade-offs for the most efficient competing alternatives. The selection of the "best" alternative from the non-dominated solution set is outside of the analysis. This process is illustrated in Figure 1, where several alternatives with inferior performance are eliminated for a two-objective problem. Extensions of this approach include the Hop-Skip-and-Jump methods for generating efficient solutions (Brill, et al. 1982), intending to generate a wide variety of solutions with very different, but still Pareto-efficient/non-dominated, performance.
The second set of methods employs various approaches to reducing the non-dominated solution set to a single "best" alternative. These approaches may use multiattribute utility theory (Keeney and Raiffa 1976), prior assessments of weights (Lund 1994), geometric definitions of best (Zeleny 1974), sequential comparisons of alternative trade-offs (Haimes and Hall 1974), and other iterative methods.

Of these classical multiobjective analysis methods, only some elementary methods for screening out inferior solutions and illustrating tradeoffs and weighting methods are used commonly. Most other methods have not been widely employed, particularly for problems involving conflict among competing parties. Classically, these multi-decision maker problems have been recognized as particularly difficult problems for analysis (Cohon 1978).

**Multiple Decision-Maker Analysis**

Conflicts involving water resources almost always involve multiple decision-makers. Theoretically, such problems can be analyzed using welfare economics, involving the aggregation of individual utility functions. The practical analysis of decision problems involving multiple decision makers has generally involved the use of non-dominated/Pareto-optimal solution set generation techniques or the application of game theory.

Methods for comparing the multi-objective performance of a wide range of alternatives, illustrated in Figure 1 above, can have several roles in multi-decision maker conflict resolution problems. First, if all the relevant objectives of each party can be represented, inefficient alternatives can be screened out, helping the parties focus their deliberations on the remaining efficient alternatives. Second, to help the parties in their negotiations among the remaining alternatives, the multi-objective comparison of performance provides quantitative evaluation of the trade-offs inherent in selections among alternatives. This trade-off assessment can aid both in negotiations to select an alternative (assuming parties choose to compromise within this set) and in the development of new alternatives that would be both efficient and perhaps more likely to gain acceptance.

A more pointed use of analysis in conflict resolution is the use of game theory in negotiations and the prelude to negotiations (Raiffa 1982). There is a some literature on the application of game theory to water resource problems, but not a great deal (Loucks 1990; Rogers 1969; Kilgore, et al. 1992; Okada and Mikami 1992).

Resource allocation or zero-sum games involving a single issue, such as negotiating a sales price, are the most common form of analysis for general negotiation situations, reflecting problems where one side loses at the expense of another. The analysis for two-party and multi-
party single-issue allocation games, such as cost allocation problems, is fairly well explored (Loehman 1995; Becker and Easter 1995). Some analysis and empirical results also are available for multi-party, multi-issue problems (Raiffa 1982).

The popularization of cooperative game theory principles also has become the basis for much of the professional literature on conflict resolution/collaborative problem-solving techniques (Schelling 1960; Dunning 1986; Delli Priscoli 1990; McKinney 1990). In cooperative game theory, there is assumed to be a solution which satisfies the parties, and the problem remains of how to get the parties to approach that solution. In the simplest cooperative games, two parties grope for a solution which is to their mutual satisfaction in an environment where either they cannot communicate (Schelling 1960) or the performance of each alternative is fraught with uncertainty, hindering the ability of each party to agree on what should be tried next.

Despite a great deal of literature on the theory and application of game theory, and the quantitative nature of much of this theory, these ideas have not been extensively incorporated into quantitative analysis of water resource conflicts. Where these ideas have been used, it has typically been in a qualitative way, for conceptual insight or explanation, rather than quantitatively to suggest promising strategies for one party or promising solutions for a group of stakeholders. Analytical and empirical results from a game theory perspective should be able to provide more insight into how system models can be better applied to conflict resolution settings.

Aside from game theory analysis of conflicts, the roles of models in negotiations have been divided into the use of models to prepare for negotiations and the use of models as a shared support system for ongoing negotiations (Theissen and Loucks 1992). In preparing for negotiations, models can be used by single or allied parties to develop negotiation strategies, positions, and proposals and to analyze positions proposed by others. As a shared support system for negotiations, models can serve a supporting role, allowing rapid evaluation of proposals from a common technical understanding of the system. This shared supporting role also can be made the core of a negotiating process, formalizing the progress of negotiations. A few controlled experiments have shown these effects to some degree (Reitsma, et al. 1996).

**How is Conflict Resolution Different?**

What makes conflict resolution problems different from other water resource problems for which computer models have demonstrated success? In most conflict resolution problems:

1. System objectives are not defined clearly. There is a lack of decision-maker consensus on objectives for system performance (Liebman 1976).

2. Performance measures are not quantified sufficiently to measure progress toward an objective. Decision makers often are unable to specify quantitative indicators of preferred performance (objective functions) (Liebman 1976; Loucks 1990).

3. Decision-makers at the political policy level are unfamiliar with models and modeling (Liebman 1976; Gass 1984). Policy-makers also may be unused to scientific or technical approaches to decision-making.

4. Policy-makers may be more comfortable and familiar with adversarial forms of decision-making.

5. Political decision-makers are distracted by other matters and typically have little time to become familiar with the technical details and models important for understanding the problem and potential solutions.

6. The major objectives of most political decision-makers are predominantly beyond the scope of the water resource conflict at issue. Even if genuinely concerned with solving the problem well, re-election, higher office, or broader legislative objectives are likely to overshadow solutions to the narrower water resources problem. For the political-level decision-maker, the solution to the water resource problem (or deferral of solution to this problem) is but a small part of a larger and broader set of political objectives.

There are many conflict resolution problems where water resource systems analysis will be unable to help, particularly in the short run. This can occur for several reasons:

1. The temporal scale of specific policy decisions and analysis are poorly matched. By the time modeling analysis is completed, policy decisions have already been made. (Often the outlines of the decision exists before a systems study is commissioned.) In water resources, policy decisions typically are motivated by floods, droughts, spills, or other episodes which demand political attention (Bulkley 1990). These events and their aftermath are typically too short to conduct new analyses from scratch. This means that the technical basis for policy decisions is usually based on studies conducted before the most recent episode. However, today's too-late policy analysis, if well done, might be useful when the issue next comes round.

2. The solution to the water issue is driven by larger ideological or political factors. Any analysis, no matter...
how timely or well done, can be overwhelmed. The
system objectives modeled might include traditional
engineering, economic, or environmental criteria. The
real political objectives in the short term might be
"further the application of privatization (or public
control) throughout the jurisdiction" or to retain the
political support of a particular stakeholder group (which
already advocates a particular solution). Such objectives
would be considered illegitimate for public policy analysis
conducted by government agencies or academia, although
they might be pursued by political advisors and might
dominate some decision processes.

3. There is insufficient political attention or wherewithal
to act on the recommendations of a good study. The
attention of high level policy-makers is usually distracted
by non-water resource management issues. Even when
attention is available, it may be insufficient to craft
effective consensus for action to be taken. Even where
sufficient political attention and consensus exists, there
may be insufficient financial resources, legal authority, or
time until the next election to implement the agreed-upon
solution. It is often easier to continue or table a conflict
than to address or change it.

Aside from incremental effects on near-term decisions, in
most of these cases, good analysis must stand the test of
time to be appreciated, contributing mostly over the long
term to the resolution of conflicts. The influence of good
systems analysis is often indirect and delayed, interpreted
by middle and senior staff for use in the next "crisis."

Modeling Approaches

A great deal has been written about particular
formulations and numerical solution methods for
multiobjective reservoir analysis problems. Relatively
little has been written about the role of modeling for
resolving conflicts within the larger planning and
political context.

As engineers and planners, we believe that our modeling
tools can help in 1) better technical understanding of the
problem, 2) defining solution objectives, 3) developing
promising alternative solutions, 4) evaluating the
performance of alternative solutions, 5) providing
technical confidence in the solution agreed upon, and 6)
perhaps provide a forum for negotiations. To be effective,
our modeling efforts must make these contributions
within a larger, less technical, and more political
planning process. How can our modeling activities be
most usefully organized to provide these services within
a political and planning environment fraught with many
decision makers, conflict, distrust, and uneven levels of
technical understanding and resources?

Three settings for modeling development and use are
discussed below, as summarized in Table 1. These are
probably not the only ways that modeling can be used in
larger planning and policy processes. Certainly, Table 1
could admit many other possibilities. However, the
discussion here is confined to three non-exhaustive
possibilities. It appears that each approach is likely to be
more or less suitable for different planning and political
situations.

<table>
<thead>
<tr>
<th>Modeling Setting</th>
<th>Number of Models</th>
<th>Number of Developers</th>
<th>Number of Users</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monolithic Development and Use</td>
<td>1</td>
<td>1</td>
<td>1 or many</td>
</tr>
<tr>
<td>Pluralistic Development and Use</td>
<td>many</td>
<td>many</td>
<td>many</td>
</tr>
<tr>
<td>Shared Vision Modeling</td>
<td>1</td>
<td>common development</td>
<td>many and common</td>
</tr>
</tbody>
</table>

Table 1: Taxonomy of Modeling Settings for Conflict Resolution
1. Monolithic Model Development and Use:

Historically, computer models for water resource problems have been developed and run by a single authoritative entity. Usually, the model developer and user was (and usually still is) a single large agency such as a U.S. Army Corps of Engineers District or Division, a U.S. Bureau of Reclamation office, a state water management agency, or the agency in charge of a local water project, such as a city water department or irrigation district. In this approach, only one agency (or its consultants) undertakes modeling, and usually all model runs are conducted by that single agency.

Having a single modeling authority for a water resource system was necessary and fairly efficient in the initial development of these resources. Historically, modeling expertise was relatively rare and the hardware, personnel, and data needed for modeling were beyond the capabilities of most water interests. It was usually impossible practically to have more than a monolithic approach to development and use of computer models. This monolithic approach also benefited from a greater consensus (somewhat less conflict) regarding the purposes of water resource systems and the agency responsible for water resource development had a greater mandate to approach (and model) the problem largely as they saw fit. These practical and political conditions no longer exist for most American water resource systems. Nevertheless, we have inherited computer models and this monolithic institutional tradition of computer model use.

A variant on the monolithic modeling setting is where a single agreed-upon model exists, developed by a single authoritative party, but is distributed to each party for use. This modeling approach is commonly proposed by academic, consulting, and agency model developers. However, the distribution of such models to technically capable parties will typically lead to desires to improve the model for purposes and concerns peculiar to each party. This can lead to new, divergent versions of the formerly central model and result in diminution of central modeling authority, as local modeling capability develops.

The monolithic approach to development and use of models remains applicable to many water resource problems, where the problem definition is precise and well-accepted, the modeling agency is seen as being the authority on the subject, and where technical resources for modeling the problem are scarce. Examples of this would generally include modeling urban water distribution systems for fire flow, many cases of local flood control, real-time system operation and forecasting problems, and many cases of water demand modeling. Most of these problems are nicely single-objective or more narrowly technical (such as real-time operations and forecasting), and less related to more conflict-prone policy issues. In such cases, one would hypothesize that a single agency can best provide the functions of modeling discussed above.

2. Pluralistic Model Development and Use:

It has become more common for several agencies or interest groups to develop and use different models of the same system from different perspectives, or to adapt and use an initially common model from different interest-based perspectives.

For California's Central Valley, there are currently five major models of hydrodynamics and salinity transport in the Sacramento-San Joaquin delta. Most of these models were developed by three different groups (agencies, universities, and consulting firms), and have been adapted and used differently by about a dozen different agencies, consulting firms, non-governmental organizations, and universities. There are also three major spreadsheet models of the system and several other more aggregated models, including one model developed by an environmental organization. Currently, at least four new system models are under development, each by a different party. These models are adapted and used by several dozen agencies and consulting firms throughout the state for different purposes. Overall, several million dollars are spent each year for modeling this region's water problems. As detailed in Table 2, there are about two dozen modeling groups in the state which develop or run reservoir models for the Central Valley system.
From the traditional perspective of having a system's modeling capabilities reside in a single agency, this pluralistic approach to modeling may seem inefficient. It is certainly cumbersome and expensive. However, having multiple models and modelers provides substantial benefits for some types of problems. These benefits include:

a. Technical checking. Having several modeling groups involved in a fairly open political conflict provides opportunities for identifying the weaknesses of alternative models and model runs (as well as data). In a conflict situation, each modeling group, employed by a different basin interest or authority, can be expected to scrutinize the results and methods employed by other modeling groups. In California, such scrutiny has led to significant improvements in many models of the system.

b. Innovation. Having several competing parties conducting modeling studies of controversial problems provides some encouragement and funding for innovations in modeling technique to be applied to the problem. The innovations that are likely to develop and rise in this pluralistic setting do seem to result in a fairly high quality of analysis, although perhaps not in proportion to the additional resources expended.

c. Detailed representation. Having a variety of modeling groups active means that each major interest received perhaps a more detailed and tailored representation of its interests. This can mean a better spatial representation of the system, to represent local stakeholders and those concerned with specific parts of the system, and a representation of system performance better tailored to each stakeholder's concerns.

d. Trust in modeling. Each group having its own modelers provides an institutional setting where each stakeholder can become better acquainted with modeling and model representations of their systems and objectives. Each party also can feel comfortable in receiving independent technical input from its own people, familiar with that party's technical and political perspective.

e. Accountability. With several active and independent model groups, it becomes possible to provide a higher level of competition and criticism of specific important modeling efforts. Thus, the particular runs of a model being considered for policy-making can receive a higher level of external scrutiny from people familiar with the system. This leaves the developers of these models more publicly and professionally accountable for their work.

f. Political balance of technical power. For intensely political and detailed conflicts, each side may require its own technical specialists and models to feel confident in any solution or analysis and for use in adversarial proceedings, such as court or regulatory settings. Even where this is not an advantage, it may be an unavoidable political necessity, especially for long-standing conflicts.

Disadvantages of pluralism in modeling for conflict resolution also are apparent:

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**Table 2: Major Groups Modeling the Reservoir System of California's Central Valley**

<table>
<thead>
<tr>
<th>Sector</th>
<th>Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>State</td>
<td>Department of Water Resources</td>
</tr>
<tr>
<td></td>
<td>Planning Group</td>
</tr>
<tr>
<td></td>
<td>Operations Group</td>
</tr>
<tr>
<td>Federal</td>
<td>Bureau of Reclamation</td>
</tr>
<tr>
<td></td>
<td>Planning Group</td>
</tr>
<tr>
<td></td>
<td>Operations Group</td>
</tr>
<tr>
<td></td>
<td>Fish and Wildlife Service</td>
</tr>
<tr>
<td>Federal-State</td>
<td>CALFED (State-Federal Consortium)</td>
</tr>
<tr>
<td>Local</td>
<td>Contra Costa Water District</td>
</tr>
<tr>
<td></td>
<td>Metropolitan Water District</td>
</tr>
<tr>
<td></td>
<td>East Bay Municipal Utility District</td>
</tr>
<tr>
<td></td>
<td>City of San Francisco</td>
</tr>
<tr>
<td></td>
<td>Santa Clara Valley Water District</td>
</tr>
<tr>
<td>Private Firms</td>
<td>Pacific Gas &amp; Electric</td>
</tr>
<tr>
<td>Consulting Firms</td>
<td>about 12 active firms, some large, but mostly small firms headed by PhDs</td>
</tr>
<tr>
<td>Universities</td>
<td>University of California</td>
</tr>
<tr>
<td>Non-Governmental</td>
<td>Natural Heritage Institute</td>
</tr>
<tr>
<td></td>
<td>The Bay Institute</td>
</tr>
<tr>
<td></td>
<td>Environmental Defense Fund</td>
</tr>
</tbody>
</table>
a. Cost and modeling resources. Pluralistic model development and use is certainly more costly, financially and in terms of skilled personnel. Maintaining a modeling group for each major stakeholder is likely to be significantly more expensive than maintaining a single high-quality modeling group.

b. Time for coordination and use of results. With each group having its own model or modelers, any major new proposal must be examined by each group, and often adapted to each group's model. This can require a great deal of time, personnel, and financial resources to provide confidence or criticism of the proposal.

c. Distraction. The greater attention required for local modeling and model development may distract from cooperative efforts, either for overall system modeling or creative aspects of solving the system's technical and policy problems. A significant Tower of Modeling Babel can sometimes result, where most parties to the conflict do not have time or resources to understand, evaluate, develop, or utilize the wide range of innovations available.

d. Confusion. Regulatory agencies can find conflicting modeling results to be an impediment to decision-making or the use of technical information for decision-making.

e. Additional conflict over modeling details. It is not uncommon for modelers to disagree regarding how to best represent a particular system or its details, including input data and parameter values, equation formulation, etc. Such disagreements can create additional conflict, particularly where stakeholders attempt to use their models in adversarial regulatory or judicial proceedings.

If the water resource problem is truly important, we can usually afford pluralistic modeling, and in many ways it matches well with the prevailing pluralistic and competitive/adversarial political decision-making system. If the problem already has firmly established stakeholders, each with substantial independent technical expertise, this approach may be unavoidable practically.

We know little about how to effectively structure technical activities in such a highly decentralized and political environment, except from an adversarial perspective. In California's Central Valley and Bay-Delta system, a technical group called the Bay-Delta Modeling Forum has been active in the last several years, arranging workshops, model review, and technical discussions to improve the effectiveness of computer model use in addressing this region's water resource problems. The group's active membership consists of technical people from most of the major interest groups with active participation from consulting and academic modelers as well.

3. Shared Vision Modeling:

Shared vision modeling is the common development of a single model or modeling framework by a diverse group of stakeholders (Loucks 1990; Theissen and Loucks 1992; Palmer and Keyes 1993; Keyes and Palmer 1993, 1995; Werick and Whipple 1994). The fundamental concept is that those that will be impacted by water resource decisions that result from the model should be provided the opportunity to participate in model design, development, and evaluation. This overly democratic goal is tempered by recognizing that all participants can not effectively contribute to all components of the modeling process. System operators, stakeholders, and agencies are provided the opportunity to contribute when their contributions are most appropriate in the modeling process. A goal of the modeling process is to provide all interested parties with a tool that increases understanding of the conflict and the ability to evaluate potential trade-offs. The model is typically developed by a single, often neutral, entity with very close consultation and review by technical representatives from each stakeholder or stakeholder group. The model is intended to be approved by the individual stakeholders and to function in each of their home offices, with a fixed common authoritative model version and documentation.

A first step in the creation of shared vision models is defining who will use the model and the manner in which it will be used. This step ensures that essential modeling decisions, such as the time-step, level of detail, data needs, geographic region included, platform and hardware requirements, model type (prescriptive vs. descriptive), and user interface, are in sync with the intended users and uses. This step implicitly suggests the need to develop a team of participants early in the modeling process to ensure that the answer to these questions represents the interests of a wide range of participants. The result of this effort is a clear definition of the questions the model will answer and precisely how well they must be answered to be useful in the particular decision making environment. This first step is essential in creating the shared vision portion of shared vision modeling.

Next, the modeling functions and requirements are translated into a common model. The first intent is to create a shared understanding and vision of the overall system in the form of this common model. The model development process allows the technical personnel from the different interests to work together to develop a higher degree of consensus on how the system works and to identify and quantify relevant performance criteria.
The model development process is intended to take these mostly technical decisions out from the political spotlight, and remove as many technical questions disagreements as possible from the conflict. If one can arrive at agreement on what is contained in the model, then later efforts can focus on interpretation of the results, rather than arguments about model content. Arriving at a consensus about model construction is not easy, and model development will progress much more slowly than if performed by a single group with a single perspective. However, the reward of the shared model building process is the development of a tool which can be endorsed by all participants as appropriately representing the system under study.

Once a common vision of the system is obtained (and this is typically based on the status quo or current condition), the model can be used to develop and evaluate alternatives. The process of developing this model often is seen as a prelude to the process of developing and evaluating promising solution alternatives and informed and meaningful negotiations among stakeholders.

The second intent of this approach is to create a technically-based forum where the parties can negotiate. These negotiations are facilitated, once confidence in the common model has been achieved. Once a "shared vision" model has been developed and agreed upon, it can be used as a basis for developing, evaluating, and refining the details of management alternatives as part of a negotiating process.

The overall approach is seen as an extension of classical engineering-planning to more pluralistic decision-making circumstances (Werick and Whipple 1994). Such an approach provides a formalization of commonly advocated collaborative dispute-resolution approaches in water resources (McKinney 1990).

Two techniques have been found useful in shared vision modeling. The first, careful prototyping, is a common systems engineering technique. This calls for the systematic development of a series of increasingly more detailed models, rather than the development of a single model version. This process encourages a number of desirable features over time, including the development of ‘mock’ models that can be critiqued and improved, incorporation of increasing model detail only when it is shown important in decision making, and the opportunity to train people in the details of the system slowly over time.

The second technique is a demonstration of the model in decision making. This has been applied both in terms of ‘virtual droughts’ and ‘virtual floods.’ The notion is that the model can best be critiqued when required to support a decision process that is as ‘real’ as possible. If virtual events can be effectively staged, they will serve as clear indicators of the model’s strengths and weaknesses in decision support (Werick, et al. 1994).

Shared Vision Modeling, like other consensus building processes, requires that there be a strong motivation among the stakeholders to develop a consensus. This usually occurs only when the parties believe they can achieve a desirable goal through consensus building that can otherwise not be achieved. Consensus processes often are initiated only after other approaches have failed and the only steps remaining are litigation. Incentives, other than the fear of litigation, do exist however. The shared vision approach requires some incentive to collaborate among diverse institutions with somewhat conflicting interests. Often this has taken the form of Federal financial support. Federal, state, or local monies may become available when a water resources conflict has escalated to the point that decision-makers see the disadvantages of the status quo outweighing the uncertainties of a consensus process and authority for the development of the shared vision model. Such incentives also could be imposed judicially, perhaps through a watermaster, or by higher regulatory authorities. A shared vision approach also could arise from a consensus of stakeholders, seeking to avoid legal or regulatory proceedings. Without significant incentive to participate actively in a shared vision collaborative process, a single party can actively or passively delay the process, maintaining the status quo or allowing preparation for other legal or political activities related to the conflict.

Shared vision modeling/conflict resolution appears to be more promising when applied to relatively new or low-intensity conflicts before legal or political alternatives have been considered or for higher-intensity conflicts where agreements have been made or incentives have been imposed to maintain broad dedication to the process.

Favorable Circumstances and Roles for Alternative Modeling Settings

From this discussion, several hypotheses are suggested for when each form of modeling is likely to predominate, and perhaps be most successful (in a relative sense). These appear in Table 3. The potential functions of each modeling setting for conflict resolution are hypothesized in Table 4.
Table 3: Hypothesized Circumstances Favorable to Each Modeling Setting

<table>
<thead>
<tr>
<th>Modeling Setting</th>
<th>Favorable Circumstances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monolithic Development and Use</td>
<td>Consensus of objectives, lack of modeling resources, trust in a central modeling authority, pre-existing authoritative model</td>
</tr>
<tr>
<td>Pluralistic Development and Use</td>
<td>Many stakeholders with modeling expertise, lack of trust, lack of agreed objectives or understanding of the system</td>
</tr>
<tr>
<td>Shared Vision Modeling</td>
<td>Newer conflicts, modest stakeholder modeling capacity, neutral model sponsor, incentive to collaborate</td>
</tr>
</tbody>
</table>

Table 4: Roles of Modeling for Alternative Modeling Settings

<table>
<thead>
<tr>
<th>Model Role</th>
<th>Monolithic Development and Use</th>
<th>Pluralistic Development and Use</th>
<th>Shared Vision Modeling</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Understanding problem</td>
<td>For authoritative agency; others accept this understanding, perhaps with consultation</td>
<td>Each model represents its own understanding</td>
<td>All parties agree to same or similar understanding</td>
</tr>
<tr>
<td>2. Define objectives</td>
<td>Modeling agency defines objectives, perhaps with input from other parties</td>
<td>Each party defines its own objectives</td>
<td>All parties define, discuss, and contribute objectives</td>
</tr>
<tr>
<td>3. Developing alternatives</td>
<td>Modeling agency develops or represents proposed alternatives</td>
<td>Alternatives developed separately by each party</td>
<td>Alternatives developed in common and separately</td>
</tr>
<tr>
<td>4. Evaluate alternatives</td>
<td>Central evaluation of proposed alternatives</td>
<td>Multiple independent evaluations of alternatives</td>
<td>Common standard evaluation of proposed alternatives</td>
</tr>
<tr>
<td>5. Confidence in solutions</td>
<td>Provided by agreed modeling authority</td>
<td>From a agreement of independent models and parties' trust in their own models</td>
<td>Provided by broad consensus on single model</td>
</tr>
<tr>
<td>6. Negotiation aid</td>
<td>Model is central auxiliary for evaluation</td>
<td>Models aid parties in separately preparing and evaluating negotiating positions</td>
<td>Model has central role in developing &amp; evaluating common and party alternatives</td>
</tr>
</tbody>
</table>
Conclusions

Conflicts in water resources typically arise more from historical than technical problems. Our modeling efforts are fairly good at addressing technical problems, but can usually view most historical conflicts only from a technical perspective. There are many exogenous impediments to technical modeling efforts in attaining long-lived or substantial conflict resolutions. Thus, we should not be too hard on ourselves if our efforts come to little. The median short-term results of most modeling studies are likely to be zero.

The long-term results of our work are harder to judge, but are more promising. Good modeling studies are likely to help establish more sound frameworks for later improvements, when historical circumstances may become more favorable. In applying computer models to conflict resolution, a long view will usually be necessary. Only when great luck and skill combine are we likely to see rapid resolutions of conflict hinging on modeling studies. Rarely, if ever, will conflicts be resolved by modeling studies alone. Despite their limitations, modeling studies are likely to be cost-effective compared to most legal, media, or other political activities to resolve conflicts.

What are some directions that our profession should take to improve our effectiveness in understanding and resolving water resource conflicts? Here are some thoughts.

1. If we want to be effective in resolving water resource conflicts, we should take a fresh look at our wonderful tools from a more relevant political perspective. Game theory is a nicely quantitative and analytical theory of conflict situations which has demonstrated considerable insight into solving conflict problems. We should try to make greater use of it.

2. We need to better develop the management of our technical tools within common institutional contexts. We largely know how to develop and use models in a monolithic agency. We have only begun to explore approaches appropriate in more common contemporary situations where many decision makers are important. The development of cross-stakeholder technical groups, such as the Bay-Delta Modeling Forum, may improve the flow of technical information across parties while retaining the benefits of pluralistic modeling settings. Use of the internet might help broaden the base of monolithic model development and use or aid the communications needed for Shared Vision modeling.

3. We should broaden our systems analyses to include the institutional contexts of water resource conflicts. Solving the physical problems is usually insufficient. We should draw from economics, political science, and law to help us develop and analyze alternative institutional forms for managing water resources and the role of technical work for these problems. The development of institutions for managing a conflict is likely to be a necessary condition for technical studies to be effective. Institutions for producing effective long-term studies and facilitating more flexible management seem particularly desirable.

4. Alternatively, given the difficulty of conflict problems, perhaps we should better define classes of conflict problems where modeling analysis is unlikely to be effective. This would allow us to avoid these problems and focus our efforts on problems which hold more promise. The more difficult conflict problems might become easier once we have improved and demonstrated our effectiveness with easier conflict problems.

References


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