Beyond Common Knowledge:
The Use of Technical Information in Policymaking

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Chapter 1:
Introduction

PROBLEM DESCRIPTION

People worldwide are struggling to resolve significant conflicts over water and other natural resources. Examples include nationally publicized efforts in California, central and southern Florida, and the Pacific Northwest as well as in Central Asia, the Middle East, and elsewhere. In each of these policy debates, groups representing conflicting interests are working to resolve problems relevant to them. All of these processes involve complex systems with high degrees of physical, social, economic and environmental interaction. As a result, there is often extensive technical work involved with attempts to change policy.

Stimulated by increasing demand for technical information related to policymaking, this thesis explores how technical information and policy-making activities interact. Many participants in these contentious policy debates have expressed dissatisfaction with the process and resulting policy outcomes (or lack of significant change). While demand for technical information is clearly increasing, how technical information affects policy outcomes often is not well understood – by the people requesting it or the people responsible for producing it. This thesis explores the interaction of technical information and policymaking with the intent of helping professional analysts provide technical information useful to policymakers.

ORGANIZATION OF REPORT

This report is organized into six chapters. Chapter 2 provides a summary of relevant engineering and political science literature about policy-making processes. Key theories about policymaking are presented to help analysts form a better understanding of policy-making processes. Theories describing different uses of technical information in policy-making activities are presented along with ideas regarding why technical analysis can never replace the political process. Suggestions for how technical analysis might be adapted to work better within policy-making activities are offered.

Chapter 3 describes an application of technical analysis designed to help resolve conflict between endangered species affected by reservoir operation in Arizona. The application illustrates how technical analyses can help policymakers consider uncertainty when making decisions. The policy context and problems faced during the study are described. The chapter presents some technical issues related to analyzing and evaluating data using indicators, describes the formulation of a Monte Carlo model to consider eagle nesting behavior explicitly during reservoir operations decisions, and presents results and implications from the analysis.

Chapter 4 presents application of a network flow optimization model to the water management system in central and southern Florida. This application illustrates another use of technical information for policymaking. The optimization modeling was performed to help other analysts better understand the system, without intending to share the technical information directly with policy participants. A description of the problem is presented along with model formulation. The chapter offers some methods for modeling evaporation and seepage with network flow models. Finally, study results and implications are presented.

Chapter 5 compares experiences gained participating in technical studies related to water resource policy debates with the policy-making theories presented in Chapter 2. Each project is summarized and general observations about policy context, problems faced, and perceived impacts of the study are presented. The frequent mismatch between what policymakers want and what analysts provide is described. Reasons for the mismatch are explored, and suggestions for reducing the disparity are offered.

Chapter 6 provides some overall conclusions of this work.

Chapter 2:

Integrating Knowledge and Power

INTRODUCTION

Significant social changes have sparked long-term conflicts over natural resource use. Increasingly diverse groups are demanding changes (sometimes in the form of legal actions) from government agencies responsible for overseeing the allocation and management of water.

Notable examples include recent conflicts over resource use in Mono Lake, the Columbia River System, the Missouri River System, Central and South Florida / Everglades, and the San Francisco Bay / Sacramento Delta. These cases involve various competing interests representing environmental preservation and restoration, agricultural irrigation, and urban water supply, recreation, hydropower generation, flood control, and navigation. The policy debates are taking place at all levels of government.

One aspect of particular importance for engineers, economists, planners, and other analysts is the intensive use of technical information in these contentious policy debates. Substantial technical work has been conducted and used surrounding the conflicts mentioned above from disciplines such as hydrology, engineering, biology, chemistry, ecology, operations research and economics. Recent decisions or policy changes have involved extensive amounts of technical information as part of the solution (WRCB 1994; Fullerton 1994).

Within conflicts over water resources, demand for technical information seems to be increasing. If water resources engineers and scientists are to be helpful in forming complex water policy, it seems appropriate for engineers and scientists to better understand how technical analysis and public policymaking interact.

This chapter explores several questions related to the use of technical information in public policymaking:

- What does technical analysis offer in the policy-making process?
- How has technical analysis been used in the policy-making process?
- How successful have past technical efforts been in influencing policy?
- Can analytical methods and findings be made more effective in policymaking?

These questions are not new to the engineering profession. Similar questions have been asked periodically in the engineering literature, and explored in the context of engineering experience. This chapter reviews those insights presented in the engineering literature but also goes further and summarizes relevant political science literature on policymaking. While learning from our own professional experiences is helpful, an understanding of the policy-making process from specialists can allow for deeper and broader exploration of these questions. A summary of policy-making theories is offered to help engineers and scientists think more clearly about how analysis and policymaking interact. Finally, specific recommendations are offered to improve the effectiveness of modeling and analysis in policymaking.

INWARD VIEWS

As engineers have explored questions about analysis and modeling effectiveness in the past, they often have taken analysis to mean systems analysis (James, et al. 1969; Liebman 1976; Loucks, et al. 1985; Rogers and Fiering 1986; Loucks 1992). However, different authors have used the term systems analysis differently. In this chapter, systems analysis is defined as a structured approach to defining problems, collecting relevant data, generating and evaluating alternatives, and choosing an alternative (or alternatives) for implementation. The systems analysis approach includes the use of mathematical models, either simulation or optimization models. (Note: Rogers and Fiering (1986) limited systems analysis to include only formal optimization techniques.)

Systems Analysis: Promise and Purpose

System modelers advocate using systems analysis in planning activities based on the assumption that "an orderly, systematic, structured approach to problem solving is likely to be more efficient and effective than an informal approach" (Cohon 1978). Models allow analysts to consider many more issues simultaneously and precisely than would otherwise be possible. Furthermore, modeling provides a mechanism to predict future behavior of existing or proposed water resource systems (Loucks 1992). Models also can be used to facilitate learning about complex water systems (Liebman 1976; Loucks, et al. 1985; Loucks 1992; Lund and Palmer 1997).

The papers mentioned above all suggest that systems analysis applied to water resources and environmental planning and management should be primarily focused on helping decision makers make better decisions. Loucks suggests that modelers should strive to provide information and understanding from model applications to help "define, focus, and influence the debate about what decisions to make or actions to take" (Loucks 1992, p. 217).

Past Performance

Overall, the authors that reviewed application of systems analysis to policymaking agree that the results have been disappointing (Liebman 1976; Loucks, et al. 1985; Rogers and Fiering 1986; Loucks 1992). Cohon (1978, p. 14) noted a glaring difference between development of systems methods and their application to real problems:

> "The rather dismal success rate for the use of systems analysis in solving real problems is a sobering fact. The literature of systems analysis is filled with new mathematical techniques, theoretical discussions and extensions of existing methods, and the application of these approaches to neat hypothetical problems. There are strikingly few reports of the successful application of systems analysis to real-world public planning problems."

While systems analysis has not been as effective as we would like, Loucks, Stedinger and Shamir (1985) provide an insightful summary of how systems applications have been used (Table 2.1). They concluded that results from systems analysis studies rarely were implemented directly. However, systems analysis was used frequently for education and as inputs to policy debate. This finding is significant and will be discussed in later sections.

Table 2.1 Overall outcome of applications (Loucks, Stedinger and Shamir 1985)

Criterion	Relative frequency of occurrence
Model solution implementation	Very low
Model implementation and use by planners and policymakers	Low (policy studies); average (operation studies)
Model results entering into decision debate	High
Model results affecting institutional change	Very low
Training – technology transfer	High
Complete failure, no impact	Low / medium

Problems Applying Analysis to Policymaking

Based on their reviews of applying systems analysis to policymaking, the authors offered several reasons why they believe results have been disappointing.

Value Conflicts

Liebman (1976) points out that applying optimization models to public problems is much more difficult than applying them to better defined private or purely technical problems. (Systems analysis was first applied mostly to military problems and continues to be widely used for scheduling operations for businesses such as airlines.) To use system models to 'solve' a problem one or more objective functions must be identified. In many public problems, these objectives differ depending on whom you ask. Differing interests often lead to ill-defined problems embroiled in value conflict. Models can never answer questions about value conflicts often present in public issues. Liebman contends "… 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." (Liebman 1976, p. 105) Consequently, if systems models are used to try to 'solve' a public problem, they are destined to fail.

Limited Knowledge

Beyond the subtlety and complexity of social problems, our understanding of the world is limited. While scientific understanding has advanced considerably, we still have only begun to understand interactions between the hydrologic system we manipulate and the resulting ecological consequences. Forecasted social and economic system responses to various policy actions also are highly uncertain. Therefore, all models and analyses have limits (Rogers and Fiering 1986; Loucks et al. 1985).

These limitations often cause decision-makers and other analysts to question model validity and credibility. Questions about data reliability and uncertainty in the model results compound credibility problems. Predictions of future outcomes of actions on a complex system are always uncertain and not completely reliable. Furthermore, models and their results are often controversial because they are viewed to contribute to who wins and loses in a policy debate (Loucks 1992).

Cultural Gap

Cultural differences between modelers and decision-makers are another impediment to successful application of systems analysis in policymaking. Simply put, analysts tend to look at the world differently than most policymakers.

> “To most policy analysts, what is appealing is the detail. To most policymakers, simplicity and generality are appealing.” (Loucks et al. 1985, p. 225)

Due to fascination with more ‘realistic’ and sophisticated tools, modelers seem to lose sight of the objective to improve decision-making (Rogers and Fiering 1986, p. 149S). Furthermore, engineers and analysts have been criticized for not communicating the benefits of complex models and methods in a way that is useful to most people involved in policymaking (Loucks et al. 1985, p. 226).

Another difference that can make communication more difficult between analysts and decision-makers is their approach to resolving problems or disputes. Analysts as a group tend to rely heavily on scientific methods to resolve disputes while many decision-makers are more comfortable with an adversarial political approach.

Political System

Another interesting explanation for the mismatch between analysis and policymaking is that perhaps political systems are poorly suited to utilize systems analysis. Rogers and Fiering observe that political decisions tend to be incremental and marginal in the U.S. They observe that, "elected officials show little enthusiasm for the large, integrated water projects to which systems analysis is most applicable" (1986, p.148S). In most situations, ambitious politicians have little reason to be concerned with the long-term technical success of decisions. Short-term political success (or avoiding failure) may be much more important to them.

Questions Raised

The water resources literature regarding interaction of analysis and policymaking raises several questions about analysts' perceptions of the policy-making process. Consider the following passage for example.

> "The goal of modelers and analysts has been, and will continue to be, one of producing data, knowledge, and tools relevant to decision making. It will not be to determine the exact answer to a specific problem. Yet knowledge needed for understanding does not always correspond to knowledge needed for decisions. Model builders concerned with scholarship often have differing objectives from potential model users concerned with decisions and their political impacts. Research in the discipline of decision modeling and analysis should be tailored to the problems of action and issue clarification if it is to be relevant to decision makers." (Loucks et al. 1985, p. 228)

The engineering authors frequently use terms like knowledge, decisions and decision-makers when discussing model development and application. However, precise definitions of these terms are rarely provided. How can one produce knowledge relevant to decision making? Are there different forms of knowledge? How is knowledge used for understanding different from knowledge needed for decisions? Is knowledge a requirement for making decisions? Who are the decision-makers and how can analysts identify them? What makes information relevant to decision-makers? Answers to these questions will likely differ depending on whether an analyst or a participant in the policy-making process is asked. The political science literature on policymaking offers ideas specifically targeted to explore these questions.

POLICYMAKING DESCRIBED

Many different views of policy-making processes exist. Theories to explain policymaking have been evolving since the dawn of political science. Various theories concentrate on different aspects of policymaking. Numerous ideas from the political science literature salient for analysts desiring to improve their contribution to the policy-making process are offered below. The ideas are summarized to answer the questions who, what, why, how, and when.

Who makes policy?

The answer to this question is crucial to analysts trying to impact the policy-making process. As discussed above, the "decision-makers" are central to most technical work related to public policy.

Many people say that presidents and prime ministers, mayors and governors, legislators and bureaucrats make policy. These participants, without question, receive the most attention in the policy-making process from the public, the media and even the policy-making literature. These are the people that most often come to mind when an analyst speaks of decision-makers. However, recent theories suggest that these public figures and their actions do not make policy. Indeed, they do not even really lead policymaking, but rather, they serve as lenses that refract the diverse pressures and influences from a much broader source. Current policy-making theories assert that people from all levels of government, business, the media, interest groups and various coalitions can play a role in policymaking (Baumgartner and Jones 1993; Lindblom and Woodhouse 1993; Sabatier and Jenkins-Smith 1993).

Safety in Numbers

Participants rarely try to solve their problems as individuals. Groups of people in the policy-making process are observed to work together to try to accomplish common goals. These groups are called advocacy coalitions (Sabatier and Jenkins-Smith 1993) or partisan groups (Lindblom and Woodhouse 1993). These groups are thought to form due to the high level of

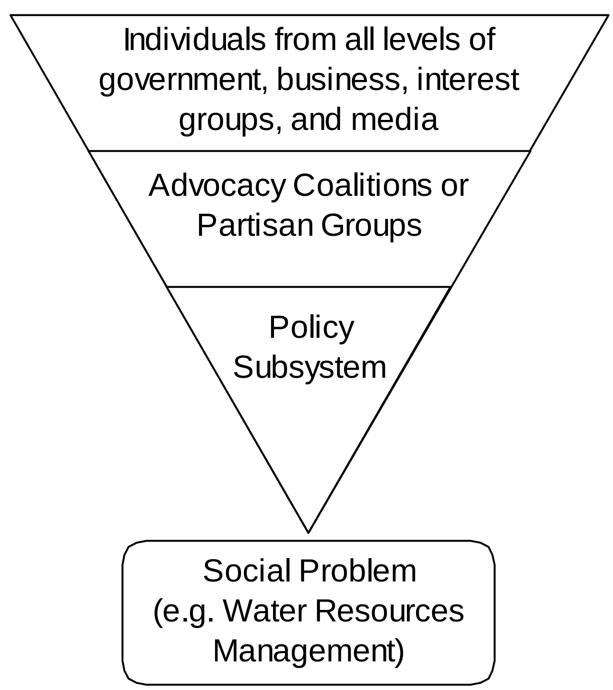

Figure 2.1 Participants in Policymaking

knowledge and expertise needed to effectively influence policy in a particular area. Sabatier and Jenkins-Smith propose that these groups are formed based on personal beliefs shared among the members.

Furthermore, players and groups coalesce into policy subsystems (also called sub governments) around issues that have a particular relevance to them (e.g. water resources management, public education, or airline deregulation). Figure 1 illustrates how many individuals from diverse backgrounds and associations tend to coalesce into coalitions working together for a common cause and that these coalitions tend to form policy subsystems that specifically focus on one area of social problem solving.

What do we mean by policymaking?

All societies face very serious problems. People naturally want to "solve" these problems. Forming solutions to a society's problems occurs by some process. We call this process policymaking.

The problems being addressed are often severe and complex; the resources are always limited. The system that has evolved to attempt to solve social problems is dynamic with the participants and rules in constant flux. Consequently, problem solving in a social context has come to mean something very different from the term problem solving as used in traditional engineering work. Lindblom and Cohen (1979, p. 4) offer an insightful definition of social problem solving:

> "By social problem solving, we mean the processes that are thought to eventuate in outcomes that by some standard are an improvement on the previously existing situation, or are presumed to so eventuate. We do not limit the term to processes that achieve ideal or even satisfactory outcomes; and in that light, "problem-attacking" is more accurate a term than "problem-solving." Nor do we limit the term to the intellectual processes through which people grapple with problems. Coin tossing is

> also a problem-solving activity. Some students of problem solving hold that "solve" implies understanding, as in solving a mathematical problem. For us, "solve" does not require an understanding of "the problem" but only an outcome as when coin tossing solves a problem of whether to turn left or right at an unfamiliar, unmarked road junction."

This difference is important for analysts to ponder. The fundamentally different approach to solving problems between the two groups is perhaps the most significant obstacle to effective communication between analysts and policy-makers.

Why do people get involved?

Sometimes understanding someone's motivation is the best way to communicate effectively with that person. The objective of policy-making efforts is to use available resources to try to accomplish goals through enacting and / or administering laws or rulings. Each participant involved in policymaking is ultimately trying to do one thing – solve problems relevant to him or her.

Not surprisingly, each person that gets involved is expected to have goals that advance his or her own private gain, such as reducing business taxes to improve his or her company's profitability. However, a participant's goals also often include some aspect of improving the public good according to their own ideals (Khrehbiel 1991; Baumgartner and Jones 1993; Lindblom and Woodhouse 1993).

How does policy form?

Several of the theories offered to describe policymaking address three components:

- Policy-making system or environment

- Actions taken by participants to affect change
- Other factors that influence policy shifts

Policy-Making Environment

A person that wants to solve a social problem does not do this in isolation. She must work within an existing system made up of laws, institutions, expectations, culture, and other people. Political scientists' views of this system have changed over the last few decades. Current thinking describes a system comprised of large numbers of participants with many conflicting values, struggling to develop and implement policies to satisfy their goals. This struggle results in high levels of conflict. In the United States, this struggle takes place in a system of decentralized authority providing for diverse veto power.

Consequently, most groups cannot implement policy without building and maintaining alliances. This need to build and maintain alliances causes players to interact with each other in ways to try to achieve agreement. Due to large demands and limited resources, Weiss (1977a) expects policy-making participants to be concerned more with negotiating differences and reconciling divergent views with minimal effort than with reaching scientifically elegant solutions. This tends to prevent groups from opposing others proposals unless they have a good reason to do so: "I'll help you get what you want, if you help me get what I want." This motivation to reconcile differences with minimal effort has large implications on how policy-makers might use technical and scientific studies and data.

Participant Actions

Within the policy-making system, participants primarily draw on two commodities to try to achieve their goals: knowledge and power. Advocates of bringing more information and systematic analysis into the policy-making process often also call for a reduction of partisan political conflict, of political maneuvering, of power plays, of "politics". These advocates claim that using more knowledge and less power can improve the policy-making process. While knowledge and power may be substituted for each other somewhat, recent theories suggest that players must use both to be successful over a long term.

> "In a world of scarce resources, those who do not learn are at a competitive disadvantage in realizing their goals. Raw political power may carry the day against superior evidence, but the cost to one's credibility in a democratic society can be considerable. Moreover, resources expended – particularly in the form of favors called in – are not available for future use. Thus those who can effectively marshal persuasive evidence, thereby conserving their political resources, are more likely to win in the long run than those who neglect technical arguments" (Sabatier and Jenkins-Smith 1993, p. 44).

A player's ability to marshal persuasive evidence obviously depends on that player's knowledge of the topic being debated. However, as mentioned earlier, knowledge is not a homogeneous commodity. Loucks, Stedinger and Shamir (1985) suggested that knowledge useful to gain understanding could be different from the knowledge needed to make policy decisions. If there are different types of knowledge, then what are they, and can those differences be usefully identified to help analysts provide information that is more relevant to the policy-making game?

Understanding Knowledge

Knowledge can differ by degree (familiarity versus understanding) and by method obtained (experience versus study, induction, deduction, or faith). Furthermore, people differ by the amount and quality of knowledge they posses. In a thought provoking exploration of knowledge and its application to policymaking, Lindblom and Cohen (1979) classify knowledge into two different types based on how the knowledge is acquired: "ordinary knowledge" and "professional social inquiry" (PSI). The authors characterize "professional social inquiry" (PSI) as activities and information resulting from sustained, systematic, professional, or formal analysis. Lindblom and Cohen characterize any and all scientific (including academic and applied social science) and engineering studies as PSI. In contrast, they describe "ordinary knowledge" as:

> "... knowledge that does not owe its origin, testing, degree of verification, truth states, or currency to distinctive PSI professional techniques but rather to common sense, casual empiricism, or thoughtful speculation and analysis. It is highly fallible, but we shall call it knowledge even if it is false. As in the case of scientific knowledge, whether it is true or false, knowledge is knowledge to anyone who takes it as a basis for some commitment or action (p. 12)."

Lindblom and Cohen argue persuasively that ordinary knowledge is the primary source of knowledge used in social problem solving. Everyone possesses ordinary knowledge and uses it regularly. If policy-making participants draw mostly from common knowledge, how is PSI (or professional technical analysis) used in the policy-making process? This question will be explored further in the next section.

External Factors

Political scientists believe that other factors, beyond the control of participants and advocacy coalitions, can affect policy outcomes significantly. One external factor studied in depth is referred to as agenda setting. Due to constraints of time, money and people, the policy-making process cannot address an unlimited number of problems at one time. Consequently, various policy subsystems tend to focus on a small number of pressing problems (a political agenda). Furthermore, these social problems are not clearly defined and presented to players in the policy-making game, so advocates often expend significant resources trying to shape the agenda to bolster their strengths and offset their weaknesses. The media appears to play a central role in agenda setting. Studies recognize that disruptive events outside the control or influence of policy subsystems (such as droughts, floods or the recent rash of school shootings) significantly shape the agenda (Kingdon 1984; Iyengar and Kinder 1987).

When are decisions made?

Most work by systems analysts regarding water resources policy focuses on two pieces: decision-makers and decisions. Traditionally, the decision-makers must be identified and used to define the objective or objectives of the problem, and decisions are modeled as clearly identifiable and discrete events (Cohon 1978). Unfortunately, political scientists demonstrate that this view has little validity in the observed policy-making system.

Decisions, Decisions, Decisions

Participants in policymaking efforts often try to measure success or failure based on policy outcomes. Public officials will often claim credit by making statements such as “The governor passed legislation to increase funding to public schools.” However, in a game with so many players and rapidly changing conditions, it is difficult to identify explicitly the action (or actions) that cause one policy to be implemented and another to fail. Policies rarely occur based on one decision. Since policies are resultants of partisan mutual adjustment, “they are better described as happening than as decided upon” (Lindblom 1979, p. 522).

To further complicate the determination of when decisions are made, Lindblom and Woodhouse argue that policymaking should be viewed as a “never-ending process rather than a once-and-for-all settling of issues” (1993, p. 29). This evolution of policy is due to the difficulty of formulating problems, value conflicts between partisan groups and the frequent need to act before understanding the ‘problem’.

This view of constantly evolving policy without clear lines of decisions has implications for analysts regarding how “decisions” are modeled. Policymaking does not progress in an orderly fashion with clearly defined cause and effect. This view can offer insight to how analysis and models are designed and implemented to help make policymaking more effective.

Time for Change

The groups that make up the policy subsystems typically hold very divergent views, and correspondingly often desire policies very different from other groups in the subsystem. High levels of competition and broad sources of influence cause policy subsystems to be unstable, allowing for significant shifts in policy. While current theories of the policy-making process predict that large-scale, dynamic changes are possible, significant policy changes are expected to require years to develop under most circumstances.

Political scientists suggest that substantial policy changes usually take many years (a decade or more) to occur because the policy-making game is stabilized by several system parameters. These stabilizing system parameters include current culture, laws, wealth distribution, etc. and are outside the direct control of the players in each policy subsystem (Baumgartner and Jones 1993; Zaller 1992; Berry 1989; Derthick and Quirk 1985; Sabatier and Jenkins-Smith 1993; Lindblom and Woodhouse 1993).

This observation that significant policy change primarily takes place over many years provides a sobering outlook to studies expected to directly influence policy outcomes based on analytical findings. If this is true -- and experience indicates that it is -- analysts should pay much more attention to studies designed to improve long-term understanding among participants about the problems and their related systems. An emphasis should be placed on improving the quality and depth of common knowledge, and less on trying to provide specific analytical answers that are expected to directly influence the outcome of current policy debates.

Since analysts are primarily concerned with performing technical analyses and providing information to policymakers, an understanding of how policymakers use technical information should be useful.

USES OF ANALYSIS

In all political systems, people gather information, interpret data, and debate issues. Few groups have sufficient power to implement their desired policies without investing significantly to increase their knowledge. These knowledge-gathering activities are often limited and hurried, and ultimately may not be used. Over the past few decades, the government has expanded the supply of systematic information and analysis brought to bear on policymaking. Various forms of fact gathering, study, research, and interpretation of information potentially relevant to policymaking has become a massive effort engaging millions of people and thousands of groups. (Bryner 1992, Collinridge and Reeve 1986, Jasanoff 1990, Lindblom and Woodhouse 1993)

In the late 1970's, Weiss investigated how social research was being applied to governmental decision making in response to a growing concern that social research was rarely used. In the 1970's and early 1980's, when political scientists considered the role of technical information they generally argued that it is just another resource used in an advocacy fashion to advance one's interests (Wildavsky and Tenenbaum 1981). Weiss (1977a) describes research utilization as "an extraordinarily complicated phenomenon". Research and specialized knowledge (PSI) has been applied in numerous ways with differing levels of success.

Direct Application for Problem Solving

Direct application seemingly has been the goal of many modeling studies reviewed in the engineering literature. This use of research involves a direct and instrumental application of technical information to an adapted solution. Implicit in this model is a sense that there is a consensus on goals. Weiss found that this use of research rarely occurred, consistent with the findings of Loucks, Stedinger and Shamir in Table 1. Direct application of analysis tends to occur more frequently when goals are well defined and non-controversial, as with routine operating decisions such as normal reservoir system operations.

Interactive

In this case, analysis enters decision-making as part of a complex search for knowledge from a variety of sources. This type of use is called "policy oriented learning" by Sabatier and Jenkins-Smith (1993). The coalitions use research (along with sources of ordinary knowledge) to help shape their understanding. The groups then try to influence their opposing groups' views by changing their understanding, as part of the mutual adjustment process to build agreement.

Political Ammunition

This use of research most often occurs when decision-makers are not receptive to new evidence. For reasons of ideology, intellect, or interest, they have taken a stand that research evidence is not likely to shake. In such cases, research becomes ammunition for the side that finds its conclusions most congenial and supportive. This type of behavior has caused some people to believe that "scientific" studies are often commissioned just to support some view already held. One example of this type of use is the competing scientific findings of the health impacts from cigarette smoking. This type of application is more prominent when adversarial processes tend to dominate policy-making activities.

Delay

Under this scenario, research or technical studies are commissioned to prevent taking action that is more definitive. This strategy can allow players to stall policy decisions to avoid having to make a potentially unpopular decision, or to delay action indefinitely or until they believe conditions will be more in their favor. This strategy also can be employed to “save face” on a controversial issue. Groups interested in maintaining the status quo in the face of controversy or uncertainty most commonly employ this tactic.

Knowledge Driven

This type of use was observed when research was used for policymaking not so much because there is an issue pending that requires clarification as because research had revealed an opportunity that could be exploited. Examples of this use generally come from the physical sciences, such as the development of the transistor or inexpensive microchips.

Enlightenment

In her study, Weiss concluded that social research gradually reshapes the character of policy issues or even redefines the policy agenda. These far-reaching policy changes are thought to be the result of an accumulation of research results over time. Weiss concurred with others that direct use of research to policymaking occurs. She found that the dominant use of social research is for “enlightenment”. Weiss (1977b) argues that:

> “… research actually affects policy less through problem solving or social engineering than through ... “enlightenment”. The studies ... suggest that

> the major effect of research on policy may be the gradual sedimentation of insights, theories, concepts, and ways of looking at the world."

This gradual sedimentation of research contributions has been labeled the "enlightenment function" and as one might expect, this sort of change occurs over long periods (on the order of a decade or more). Lindblom and Cohen (1979) support the concept of the enlightenment function. They argue that the most likely way for professional analysis to impact policymaking is by gradually reshaping ordinary knowledge through the cumulative effect of findings from different studies.

LIMITS OF ANALYSIS

Many people argue that bringing more information and systematic analysis into the policy-making process will help. If this is true then why, given the obvious merits of analysis, and the ever-increasing supply of technical information, is analysis not used more often in direct decision making? Why are decisions not made using reasoned debate more and politics less?

Several authors conclude that despite the overwhelming abundance of technical information, the right kind of information often is not available to the people that need it to address their particular problem. It seems that a great deal of the work by academics and professional analysts goes unused because government officials and other policymakers do not find the information presented to them to be useful (Lindblom and Cohen 1979; Collinridge and Reeve 1986; Bryner 1992). Beyond the availability of pertinent information, other limitations prevent wholesale substitution of analysis for politics.

Conflict of Values

As mentioned before, to make policy solely through analysis would require an agreement of interests or values among all individuals and groups. This rarely occurs. Usually an action that is beneficial for some groups will likely be a disadvantage for others. While analysis can provide insights into possible tradeoffs, it can rarely provide one clear-cut answer that is compelling to all groups with different values. This is the issue that Cohon (1978) addressed by suggesting the use of classical multi-objective problem solving techniques.

Analytical Results Provoke Disagreement

In some cases, rather than bringing resolution, analysis can actually widen the rift between competing coalitions. Lindblom and Woodhouse observe that: "A peculiar and not widely understood phenomenon in social analysis is that it often moves not toward agreement but spawns new questions with new disagreements (1993, p. 17)."

Fallibility

The problems we grapple with are extremely complicated and our understanding is limited. Future events are uncertain and therefore any analysis predicting future outcomes will always contain error. Even worse, much analysis has been poorly informed, superficial, or biased – performed by someone attempting to prove by questionable means what someone in power has already decided to think.

Lack of Trust

Another source of disagreement stems from differences in available data. As long as participants perceive the facts differently, analysis alone cannot settle their differences.

Furthermore, those involved in the policy debate that do not actually perform the analysis must trust fully those that do to come to resolution strictly by analysis. Otherwise, some players will reject the analysts' conclusions and the group is left to formulate a policy action through political means.

Time and Cost

Another limitation is the requirement of time and resources for systematic analysis. Quality research on complex issues often takes months if not years. Often, even after decades of study and millions of dollars spent, experts are not able to agree on issues such as the link between exposure to asbestos and development of cancer. In other situations, research is completed after political attention has moved elsewhere. Studies such as these often are never completed due to lack of support and funding.

On the other hand, policy-makers must make decisions daily and often cannot wait for "all the facts to be in". Furthermore, since analysis is recognized to be limited, public officials often wisely refuse to invest heavily in it. Consequently, most policy decisions are made using faster, cheaper methods than formal analysis: drawing on available information and largely from ordinary knowledge.

Problem Formulation

Deciding which problems to address or even "what the real problem is" with respect to adverse situations like the riots in Los Angeles do not lend themselves to analysis. Analysis can provide valuable insight to problems such as these, but ultimately it cannot solve any of them. At some point, formulating the problems to attack requires a human choice or act of will. Furthermore, there is no analytical means to determine which problems, once formulated, should receive more priority or resources on the political agenda. This has been central to the debates surrounding the California Bay-Delta system.

Cultural Gap

Several authors have observed that professional analysts and governmental officials often experience a substantial cultural gap that impedes interaction and knowledge transfer (Sabatier and Jenkins-Smith 1993; Dunn 1980; Webber 1983; Loucks, Stedinger, and Shamir 1985). These differences seem to stem largely from divergent views of "problem solving" and the knowledge necessary to solve problems.

Impaired Thinking

Lindblom argues that as a society our ability to think clearly and creatively to solve complex problems is impaired due to systematic indoctrination. He claims influences such as schooling, parents, peers and media constantly reinforce the supreme importance of maintaining the current social and political order. These widespread efforts to produce a compliant and docile population can inhibit our ability to think and create lasting habits of subservience. He argues that this impairment tends to reinforce existing economic and political elites' advantages, and reduce the intelligence of democratic problem solving (Lindblom 1990; Lindblom and Woodhouse 1993).

THE POTENTIAL INTELLIGENCE OF DEMOCRACY

> "Understanding a social problem is not always necessary for its amelioration – a simple fact still widely overlooked." (Lindblom 1979, p. 525)

Keeping the Balance

Given the limits of analysis, Lindblom and Woodhouse argue, “there is no realistic prospect of substituting analysis for political interaction on any wholesale basis; and efforts in that direction are misguided and even dangerously misleading” (1993, p. 22). Nevertheless, democratic political interaction has the potential to bring about sensible policy when analysis alone cannot.

Strategic analysis and mutual adjustment among partisan political participants are the underlying processes that bring about intelligent action (to the extent observed) in democratic systems (Lindblom and Woodhouse 1993). There is never a point in the process when thinking, research or action is ‘objective’ or ‘unbiased’. The process is fully partisan since the people commissioning and doing the analysis contribute their expectations and priorities and the people using the information shape its interpretation and application.

This “give and take” interaction can achieve a form of understanding that cannot be produced through analysis alone. Since understanding is usually pursued as a means to improve action, when a working majority agrees on a new or revised policy, the policy can be viewed as embodying a new understanding. In this sense, partisan interaction helps reach agreement on policies even when it is not possible to fully analyze and understand the issues in question.

Bounds to Reasonableness

The need to win agreement also tends to keep demands within a range likely to be considered “reasonable” or intelligent by most of those whose agreement is needed. Bish (1982 p. 118) points out that complex policy-making systems characterized by “multiplicity, redundancy, and interdependency” are more likely to result in “access, adaptive capacity, fairness, knowledge of consequences from diverse perspectives, and the incentive to seek efficient and innovative trade-offs in complex environments” than simpler decision-making frameworks. While these complex systems facilitate access and fairness, they also raise the cost of participation and contribute to uncertainty in outcomes for single decisions, single organizations, or individual participants. Because partisan groups need to gain widespread agreement, most policy actions (or decisions) are incremental. Lindblom has long observed and argued that political participants often limit their consideration of policies to those fairly close to the status quo. Because it is usually impossible to win agreement on large changes, restricting analysis to “incremental policy proposals that may be politically feasible is a way to maximize scarce time and resources (Lindblom, 1959; Lindblom, 1979; Lindblom and Woodhouse, 1993).

By focusing on small variations from existing policy, policymakers leverage available knowledge. Since new options are not tremendously different from present and past policies, much of what participants already know about existing programs will likely remain valid when evaluating new proposals. Of course, uncertainty is still substantial, but some believe errors will probably be less significant.

ADAPTING ANALYSIS TO POLITICS

Rogers and Fiering (1986) made an astute observation regarding the mismatch between traditional systems analysis methods and the U.S. policy-making process. Given the nature of the policy-making process, there is little hope of using systems analysis techniques to “solve” social problems directly. If analysts aim to improve the quality of political interaction, knowledge about the process will be useful. Some of the important ideas describing the policy-making process are summarized as follows:

- Policy-oriented decision-making is a dynamic, evolving process influenced by a multitude of players both in and out of public service.
- Policy debates will always be disjointed and political. Analysis and reason can never replace partisan interaction completely.
- Partisan groups must effectively use both power and knowledge to be successful over the long term.
- ‘Solving’ social problems does not require understanding.
- Policymaking is significantly influenced by factors outside the control of the participating groups (such as natural disasters and other uncontrollable events).
- Pluralistic mutual adjustment strives for agreement more than understanding.
- The pluralistic partisan nature of the policy-making process offers hope to find intelligent solutions to very complex problems.
- Most policy changes will be incremental, and significant changes in policy will likely require at least a decade to occur.

These ideas offer insight into how analysis can be adapted to be more effective in the policy-making process. Given the characteristics of the policy-making process, the following traits are desirable for analysis and modeling intended to improve policymaking.

Partisan Friendly

If partisan politics is the mechanism by which public policy must be made, then analysts should aim to help partisans engage in reasoned persuasion with each other (Lindblom and Woodhouse 1993). Since partisan groups (or advocacy coalitions) have incentives to learn and use ideas that can help them further their goals, they are the most likely avenues for professional analysis to enter the public policy-making process (Sabatier and Jenkins-Smith 1993). How can models and analytical information be made more partisan friendly?

Political scientists have concluded that if policy analysts want to have a significant impact on policy, they will need to abandon the role of neutral technician and adopt the role of reasoned advocate (Sabatier and Jenkins-Smith 1993; Lindblom and Woodhouse 1993; Meltsner 1976; Jenkins-Smith 1982; Nelson 1987).

Build Trust and Accessibility

If analysts want partisan groups to use their results, models should be geared to the target audience. Before the data is likely to be used, it must be credible. Gaining credibility for models and their results can be very difficult. This process often takes time, and is most likely to occur by partisan groups learning to trust the analyst as a participant in policymaking. Recent experiences with groups such as the Bay Delta Modeling Forum in California suggest that investing time with technical representatives of different coalition groups can help further trust and credibility when discussing technical data and analyses.

Another avenue to help build credibility is by making the models and their results as accessible (i.e., available and understandable) as possible. Accessibility should be targeted to the wide array of policy-making participants, not just the high level public officials. Analysts should try to raise the standard for models intended for use in public problem solving. Models should include:

- A flexible and easy to learn user interface – This will allow people to review relevant input assumptions and model results without requiring unreasonable specialized training.
- Software tools to aid in managing model inputs and results – This is to promote credibility by reducing pathways for human error.
- A clear disclosure of all important assumptions (preferably in electronic form) – Sometimes people are more interested in the assumptions used than the outcome itself and unfortunately traditional models and modeling studies do not disclose the inherent assumptions in a clear manner.
- Information regarding where the input data was obtained (called metadata) – Again designed to promote credibility by allowing a user to verify independently the source of data used.

Beyond making the models easier to use and understand, analysts should strive to make the tools and data as widely available as possible. This can be accomplished by making the models and data sets public. Furthermore, efforts to facilitate sharing of data between agencies and between models should be encouraged.

Emphasize Plausibility over Elegance

Beyond building more friendly models and providing results, analysts need to take the perhaps more difficult step, and clearly communicate how the ideas and information from the models can improve policies. This will likely require the development of at least some people knowledgeable about both the analytical methods and political policymaking to facilitate interaction between the two groups. This group of people could act as brokers between the analysts and those that could benefit from the information (Loucks et al. 1985). The driving factor in bridging the observed cultural gap discussed earlier may be to remember that most policy advocates desire to reach agreement on policies with the least amount of effort required. This leaves little room for appreciation of scientifically elegant solutions.

Stimulate Competition of Ideas

If flexible, credible models and other analytical tools are made available to partisan groups, some of the groups may use these tools to extend their ability to think about creative solutions. These tools can also help educate policy participants by helping develop an understanding of different alternatives and their potential impacts (Liebman 1976; Rogers and Fiering 1986; Lund and Palmer 1997).

Analysts also should strive to use these models to screen a wide number of alternatives to allow partisans to focus on a few good options. Optimization models can be particularly efficient when used as screening tools (Lund and Ferreira 1996). Optimization models also can be used specifically with the intent to generate a range of alternatives significantly different than those already being considered (Brill, et al. 1990; Brill, Chang, & Hopkins 1982). This approach may help stimulate creative ideas.

Support Incremental Learning

Since social problem solving ordinarily progresses through trial-and-error over long periods, models and analysis should be conducted to help partisans cope with uncertainty. One way would be to help partisans improve their understanding of these problems and figure out ways to make the inevitable errors less damaging as well as learn from mistakes more quickly.

Formulate Flexible Policies

Partisans interested in ameliorating social problems can improve their odds for success by developing policy options that respond readily to unfavorable results if necessary. Professional analysts could possibly help this process by outlining options for partisans to consider regarding how to enhance flexibility at an acceptable cost. For instance, if two alternatives are projected to provide the same benefits toward reducing a particular problem, the alternative that was implemented gradually, requiring limited testing, and providing quick feedback may be more desirable.

Systems models can be used to describe possible failures. Since future events are uncertain, analysts should promote options that limit the severity of failure. Sensitivity analysis and probabilistic analyses should be included as a standard part of model studies to help characterize and communicate risk and uncertainty.

Accelerate Learning

Another way of comparing different alternatives is based on how long it will take to learn whether the effort is on the right track. Professional analysts can help by suggesting methods for testing alternatives as part of the implementation and helping characterize the potential quality and speed of feedback available for proposed options.

Learn from the Past

Analysis and research that recalls past experiences can be helpful and persuasive. Johnson and Ford (1993) challenge engineers and analysts to use computer analysis more selectively while critically drawing from a wider array of information available in water resources planning and management. One suggestion they offer is to use case studies of previous policy debates to better understand the diversity of information available and how that information influences planning and management.

An example of this approach is a study currently underway to review past conjunctive management efforts in California to help determine how actions regarding this controversial topic might be more successful in the future. The intent is to learn from past experiences what worked and what did not.

Develop Flexible Tools

Since the policy-making process is constantly evolving, models should be developed to work well with rapidly changing demands and objectives. Recent advances in computer science have provided object-oriented design and development methods that help build in software flexibility. These methods allow software to evolve more credibly than the techniques historically used by engineers.

Modeling and Conflict Resolution

Water resources engineers and scientists are likely to be called upon with increasing frequency to provide information to help partisans in their political maneuvers.

However, if history is any indication, models and their results will rarely be implemented directly in policy decisions. For analysts that want to improve the quality of public policies, they must be strategic in how analysis is applied. Most applications reported in the literature are targeted towards direct impacts intended to occur in short times (within a few years). Recently, these efforts have been targeted to conflict resolution efforts. Many of these applications have often centered on computer-assisted negotiations or shared vision modeling (Sheer, Baeck, and Wright 1989; Theissen and Loucks 1992; Keyes and Palmer 1993, 1995; Lund and Palmer 1997).

When two or more political participants think about a policy problem, they often suggest different ideas of what should be done. Thus, participants are left with a task of resolving conflict. Political participants can approach this effort using non-rational or irrational persuasion, political power plays, or informed and reasoned persuasion. What role can analysis play in promoting reasoned persuasion as a means of conflict resolution?

The common approach is for analysts to look for aspects of the problem that if brought to light might reduce conflict and at least move some of the participants towards agreement. Analysts should recognize that for this approach to be helpful, a significant number of the participants must be ready to reach resolution. On problems mired in fixed, high conflict, and intractable issues, efforts along this line are not likely to be successful. This implies that analysts should be aware of the policy context they are being asked to participate to avoid wasting large amounts of time and money. To help determine where analysis might be most useful, Sabatier and Zafonte (1995) offer some criteria they believe would increase the likelihood of successful application of analysis to reduce conflict. Their hypotheses regarding successful professional / scientific fora are:

1. In order for scientists with quite different points of view to come to consensus and for that consensus to be accepted by the major coalitions, the technical advisory committee should include both:
    a. Scientists clearly associated with each of the major coalitions and
    b. Neutral scientists

   The chair should come from the latter. Consistent with the very concept of professional forum, however, only professionals with established reputations should be involved in the forum.

2. In order to get participation from both neutral and coalition scientists, both of the following conditions must be fulfilled:
    a. A policy stalemate exists in which all coalitions perceive themselves as potential losers and
    b. The committee's report is commissioned by policymakers from various coalitions (e.g. the legislature and/or group of agencies representing the various coalitions), or by an agency with dominant legal authority

3. Funding must come from an institution that is not perceived as being controlled by a single coalition. This will usually require funding either by
    a. A diverse legislative body or
    b. Multiple agencies (or interest groups) representing various coalitions

Take Long Term Perspective

Strong evidence indicates that technical analysis benefits policymaking most by reshaping common knowledge over long periods, not through direct application (Weiss 1977b; Lindblom and Cohen 1979). This finding has important implications for how technical analysis and research is conducted. While the research involving direct use of computers to resolve conflict is exciting to most analysts, the political science literature on policy-making offers little hope that these efforts will make large improvements in public policy. In addition to developing tools designed to become central to policy-making efforts, perhaps analysts should work to develop applications that offer the greatest potential for improving water resources policy – long term, indirect applications. Table 2 contrasts the short-term and long-term applications for analysis in policymaking.

Table 2.2 Applications of Technical Analysis to Policymaking

Short-term	Long-term
Formulate flexible alternatives	Structure long-term learning
Stimulate creative ideas	Promote policy-oriented learning
Structure debate	Provide strategic support for advocacy groups
Set bounds for negotiations	Improve ordinary knowledge
Facilitate conflict resolution	

Improve Ordinary Knowledge

Based on evidence of how technical information is used, analysts should concentrate on educational aspects of modeling and analysis. This long-term strategy for model development and model use specifically to educate a diffuse group of participants is different from historical approaches. The strategy to improve common knowledge among different participants will likely be different for different groups. The groups might be characterized as:

- General public
- Politicians interested in policy subsystem
- Agency heads
- Agency staffs
- Interest group leaders
- Media

Each of these groups has different levels of knowledge, focus, attention spans, longevity, and interest in (or tolerance for) technical detail.

Most modelers hope to see results from their efforts relatively quickly, but perhaps efforts would be more fruitful when designed to produce results over longer time horizons. This approach has implications for funding as well. Analysts should encourage agencies responsible for participation in water policy to be leaders in developing credible analysis techniques and tools that can be widely used by partisan groups over periods of ten years or more.

Model Development

Many of the modeling efforts to date started and developed with a short-term perspective (one to two years). Many "short-term" models have ended up being used for ten or more years, growing increasingly complex and more unpredictable with each incremental change. Models should be designed explicitly for long-term use, and built to accommodate frequent changes and ease of maintenance from the beginning.

Beyond the models, organization of data compiled for use with models is also important. Data such as watershed hydrology tends to last much longer and be applied more broadly than its original purposes. Historically, these data sets contain a host of assumptions that are poorly documented. These assumptions and limitations should be attached with the data set as thoroughly as possible. Even further, the field of water resource planning and management could benefit from developing standard data definitions that facilitate transfer of data between different models and databases similar to what has been developed in industrial engineering and manufacturing.

CONCLUSIONS

There are many formidable obstacles to improving social problem solving. People have limited capacities for probing social problems and proposed policy options. Analysis is also limited as discussed above, and can never replace the political process. Recognizing these limits, a strengthened competition of ideas is a core element in improving the capacity for intelligent policymaking. Perhaps this is the greatest avenue for positive contribution for professional analysts: to facilitate or improve the competition of ideas within the partisan process.

How can analysts contribute to improving the policy-making process? Perhaps the best hope is to help balance reasoned persuasion with power. Specifically, analysts should encourage participants in the policy-making process to reach policy choices based on informed analysis and thoughtful discussion when possible, and discourage setting policy exclusively through bargaining, trading of favors, voting or otherwise exerting power.

Analysts can promote thoughtful discussion over the long-term by:

- Encouraging issue-oriented learning among partisan groups
- Providing strategic support for partisan groups in their advocacy roles
- Stimulating creative thinking
- Providing tools and studies geared to improve the quality of ordinary knowledge.

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Chapter 3:
Characterizing Environmental Uncertainty for Policymaking: Alamo Reservoir, Arizona

INTRODUCTION

As discussed in Chapter 2, one way to apply technical information in policymaking is to predict possible outcomes from proposed policy changes. This chapter explores some technical issues of how to represent uncertainty for policy decisions regarding managing water and natural resources under conflict. The discussion centers on an actual case study of decision making under uncertainty.

The case study focuses on efforts by the Los Angeles District of the US Army Corps of Engineers (USACE) to evaluate policies for operating Alamo Reservoir in Arizona. The Los Angeles District faces some difficult operational decisions for Alamo Dam. The District recently participated in an interagency cooperative study to address conflicting operational objectives. The cooperative study was performed through the Bill Williams River Corridor Technical Committee (BWRCTC) made up of members from several state and federal agencies. As a supplement to the cooperative study, the Los Angeles District of the USACE commissioned a study to provide more information about some issues not studied specifically in the BWRCTC study. A large part of the second technical study (USACE 1998) provides information to help make decisions in the face of significant uncertainty, through Monte Carlo assessment of environmental performance and sensitivity analysis of performance criteria. The methods and impacts of these two technical studies designed to help make better policy decisions are evaluated to explore one role of technical information and policymaking.

SOURCES OF CONFLICT

Alamo Lake is a multiple purpose reservoir owned and operated by the U.S. Army Corps of Engineers. The dam is located in Arizona on the Bill Williams River approximately 39 river miles upstream of the confluence with the Colorado River (see Figure 1.1). The reservoir has a maximum capacity of about 1.4 million acre-feet and serves a drainage area of 4,770 square miles of broad desert valleys and irregularly distributed rugged mountain ranges. Steep gradients, impervious soil formations and fan-shaped runoff patterns tend to produce high peak discharges of relatively short duration. An average annual precipitation of 13 inches over the sparsely vegetated watershed produces a mean annual runoff of 115.4 KAF despite an average annual pan evaporation of 65 inches.

During the late 1980's, agencies responsible for managing the Bill Williams River resources and Alamo Dam and Reservoir experienced increasing conflict between their individual missions and perspectives. Much of the disagreement centered on how the Corps was operating the water conservation pool at Alamo Lake. In August 1990, believing that a cooperative effort offered the best chance to achieve a water management agreement that would help balance agency management goals, the agencies instituted an interagency planning team -- the Bill Williams River Corridor Technical Committee. The BWRCTC was charged to develop a comprehensive management plan for the Bill Williams River corridor addressing these water management objectives (BWRCTC 1994):

- *Flood Control* -- The dam was authorized by Congress to provide flood control for lower Colorado River communities downstream from Parker Dam (Lake Havasu), and protect property along the Bill Williams River corridor. Alamo Dam is operated in conjunction with the U.S. Bureau of Reclamation dams on the Colorado River to reduce flood-related damage.
- *Water Conservation and Supply* -- The entire water supply in the Bill Williams River (before reaching Lake Havasu) is entitled solely to Arizona. Bill Williams River flows that reach the Colorado River are allocated according to the "Law of the River" including the U.S. Supreme Court Decree in *Arizona v. California* of March 1964. To date, the Corps has not contracted with a user for water supply storage. The conservation pool has been used only for short-term storage of water, later released to Lake Havasu.
- *Recreation* -- The Arizona Game and Fish Department currently holds water rights for 25,000 acre-feet in the recreation pool. These rights are for fish, wildlife and recreational purposes. The Arizona State Parks Department operates and maintains boat launching ramps, campgrounds and appurtenant structures.
- *Fishery* -- Arizona Game and Fish has established a productive lake bass fishery. The productivity of the fishery is negatively affected by fluctuations in lake levels during spawning and growing seasons.
- *Endangered Species* -- Two pair of Southern Bald Eagles, a Federally listed species (recently reclassified as threatened), have nested around Alamo Lake since the early 1980's. In 1988, the U.S. Fish and Wildlife Service requested that the Corps maintain a minimum lake level of 1,100 feet to ensure sufficient forage

area for the eagles. In addition, the eagles sometimes nest in tree snags along the periphery of the lake, and reservoir operations have been modified in the past to restrict boater access and prevent nest inundation.

- *Wildlife Habitat* -- The Bill Williams River Corridor includes a National Wildlife Refuge and flows through two designated wilderness areas. The river corridor is home to various neo-tropical migratory birds and several threatened or endangered species. The wildlife habitat depends on the vitality of the riparian habitat.
- *Riparian Habitat* -- The riparian habitat along the Bill Williams River contains the last extensive native cottonwood tree stands in Arizona. The U.S. Fish and Wildlife Service believes that a significant portion of the cottonwood trees have been destroyed due to the pattern of past Alamo Dam releases.

The people trying to meet their agency's objectives learned that operating Alamo Dam to satisfy their objective often interfered with other objectives. Early efforts by agency personnel to resolve these conflicts were hampered by a lack of understanding of the different objectives and their relation to the operation of Alamo Dam. Operating a reservoir to meet multiple objectives such as flood control, recreation and water supply requires tradeoffs since they are in direct competition with one another. Beyond the traditional sources of conflict, Alamo Dam operations also affect species protected under the Endangered Species Act. The ESA places the needs of endangered species above traditional objectives such as water supply or recreation. However, on the Bill Williams

River, the District faces an even more difficult management problem – competition between listed species.

For the past twelve years, bald eagles have nested around Alamo reservoir. The eagles often nest in dead trees near the edge of the reservoir pool. If a large rain event occurs upstream of Alamo Dam the eagle nests can be inundated by rising water in the reservoir. The eagles that nest around Alamo reservoir also rely on the reservoir for forage and the U.S. Fish and Wildlife Service has requested that the water in the reservoir be kept above 1,100 feet elevation to provide adequate forage area. Furthermore, the Bill Williams River downstream of Alamo Dam flows through a National Wildlife Area and supports the last extensive native cottonwood riparian habitat in Arizona. Several species protected by the Endangered Species Act depend on this riparian habitat. The health of the riparian habitat is believed to depend heavily upon operation of Alamo dam. This chapter explores methods to provide quantitative estimates of impacts on different objectives for different reservoir operation plans. The reason for estimating impacts is to promote understanding of the interactions between competing objectives and reservoir operation. Perhaps better understanding of the problem will lead to policies that are more effective at balancing the conflicts.

POLICY CONTEXT

During the late 1980's, agencies responsible for managing resources along the Bill Williams River were in conflict over their individual goals and missions. Many of the issues related to the conflict were addressed through an interagency cooperative study performed by the Bill Williams River Corridor Technical Committee (BWRCTC) outlined in the *Proposed Water Management Plan for Alamo Dam and the Bill Williams*

River (BWRCTC 1994). Nonetheless, some significant concerns about reservoir operation were not resolved by the BWRCTC. The primary issue not resolved during the BWRCTC study was efforts to prevent bald eagle nest inundation. During recent years, some rain events have caused the water in the reservoir to rise high enough to threaten, or even submerge, eagle nests. These disruptions to eagle nesting and brooding provoked further disagreement over how Alamo reservoir should be operated. Changing planned reservoir operations to prevent inundation during a flood event seemed, at least potentially, to conflict with other agreed upon operating strategies, including those for protected species downstream. The Los Angeles District desires to develop a comprehensive long-term strategy to deal with this difficult issue of competition between species protected under the Endangered Species Act. The District felt that estimates of likely tradeoffs between competing objectives caused by different operating strategies could help craft a viable long-term strategy. The second technical study also explored using different draw-down schemes for required maintenance inspections, and applied a combined optimization / simulation modeling approach for comparison to results obtained by the BWRCTC simulation modeling study.

SOURCES OF UNCERTAINTY

Developing a strategy to balance conflicts over reservoir operation is complicated by several sources of uncertainty. Reservoir operation decisions must be made recognizing that the success of the operation is affected significantly by stochastic events. If these stochastic events can be considered explicitly, the selected operating strategy may produce better results than if the stochastic events are ignored. For the Alamo Dam policy debate, uncertainty arises from four major areas.

Ecological Response

Perhaps the greatest source of uncertainty for this policy problem is the response of the riparian habitat (and the corresponding obligate species) to changes in flow patterns in the Bill Williams River. This is an extremely complex question, but some attempt to quantify the relationship between stream flow and riparian health is necessary if Alamo Dam is to be operated to improve the health of the riparian ecosystem. A team of biologists and ecologists familiar with the Bill Williams River Corridor worked to develop a series of environmental indicators to help estimate the likely success of one reservoir operating strategy over another. Due to the complexity of the biological system, these indicators are highly uncertain.

Hydrology

Another source of uncertainty arises from the inflows into Alamo Lake. When planning an operational strategy, the stochastic properties of future inflows are an important factor to consider. Typically, a historical record of inflows is used in some manner to approximate the inflows likely to be encountered in the future. How to use the historic record to predict future inflow has been studied for many years by engineers and hydrologists, and research continues today. One approach is to construct a statistical model of the historical hydrology to allow creation of long hydrologic sequences that are statistically similar to observed inflows (Fiering 1966, Klemeš 1997). A recent study analyzing the long-term viability of the riparian habitat along the Bill Williams River and the risk of dam failure due to reservoir operations used such a statistical model for monthly inflows (Pulokas 1996).

A statistical model was not used for this study. Instead, the historical record of daily inflows (from October 1, 1928 to August 29, 1996) was used directly. Given the length of the record, an operating policy that performs well for the historical sequence can be expected to perform similarly in the future (Lund and Ferreira 1996). Another benefit of using the historical record for the hydrologic inputs is that it is generally easier for participants to understand and trust than statistical models of inflow.

Eagle Behavior

Eagle behavior is another uncertainty. Historically, the eagles nesting around Alamo Lake have chosen different sites. Where the eagles choose to nest each year directly affects release decisions if the dam is being operated to prevent nest inundation. For this study, the available historical nesting data was used to create a simple statistical model to evaluate alternative operating strategies.

Policy Implementation

Beyond the physical and biological elements of the reservoir operations problem, the reservoir manager also must deal with institutional and policy aspects. To implement any changes deemed beneficial by the modeling study, the bureaucratic and legislative policies for operation of Alamo Dam must be amended. An attempt to make significant changes to a federal reservoir operating policy requires substantial policy-related work and the outcomes of the efforts are highly uncertain. The District made strategic decisions about how to pursue implementation of a revised operating plan once agreement was forged through the BWRCTC and their sponsoring agencies.

GENERATING TECHNICAL INFORMATION

Three different reservoir-modeling packages were used to study the Alamo Reservoir system to produce technical information designed to help reduce conflicts in the Bill Williams River Corridor. The Bill Williams River Corridor Technical Committee (BWRCTC) developed and applied an HEC-5 model of the Bill Williams River system to test alternatives during their cooperative analysis. HEC-5 is a flexible and widely used data-driven reservoir simulation model.

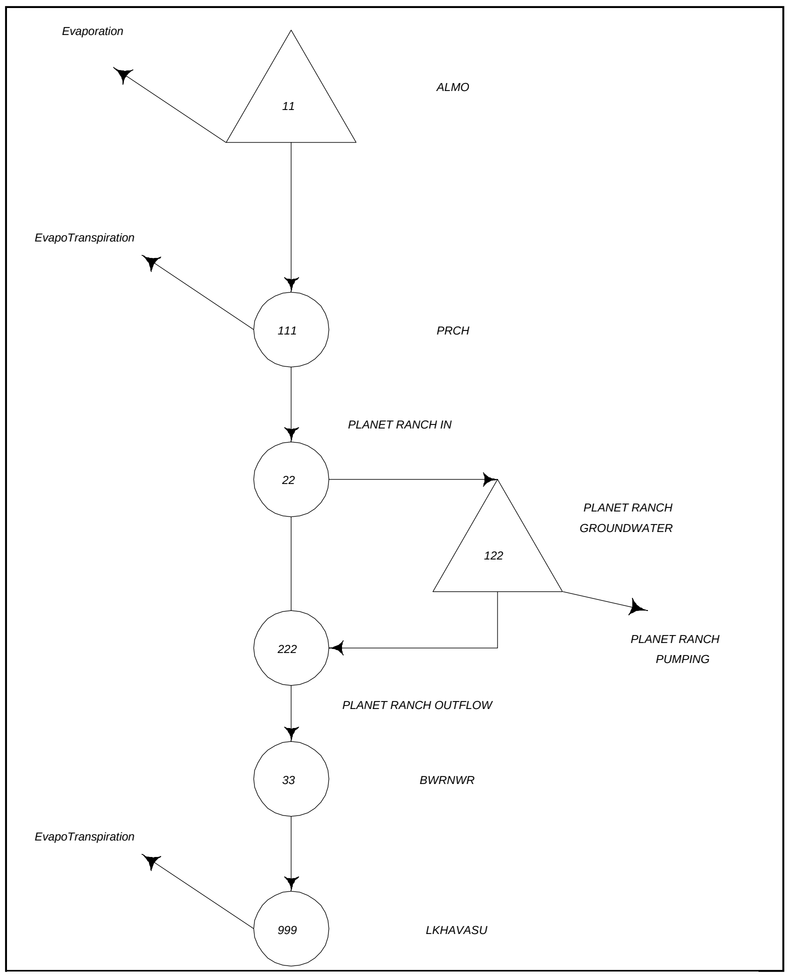

Figure 3.1 System Schematic as Modeled

For the second phase of technical modeling, the Hydrologic Engineering Center Prescriptive Reservoir Model (HEC-PRM) was used to test a combined optimization and simulation approach to compare with the operating plan recommended by the BWRCTC.

Finally, a custom simulation model was developed to refine and test the HEC-PRM model results using rule forms not currently available in HEC-5 and to facilitate probabilistic simulation of eagle nesting. This custom simulation model, referred to as AlamoSim, was configured to represent the Bill Williams River system as shown in Figure 3.1. AlamoSim uses a computational approach based on the Euler solution technique for finite difference equations as follows:

Step 1. Estimate the change in storage over a small interval Δt.

$\Delta storage = \Delta t * flow$

Calculate new value for storages based on this estimate.

$Storage_t = Storage_{t-\Delta t} + \Delta storage$

Step 2. Calculate new values for flows and other calculations in order of evaluation.

Other calculations = f(storages, flows, other calculations)

Flows = f(storages, flows, other calculations)

Step 3. Update simulation time. Stop iteration when Time ≥ simulation stop time.

$Time = Time + \Delta t$

The AlamoSim model incorporates features used in the HEC-5 model of the Alamo system that are relevant to this study, including pumping from groundwater, simplified stream and aquifer interactions, and Bill Williams River channel flows. The specifics are detailed in *Technical Considerations for Alamo Lake Operation* (USACE 1998). Both the HEC-5 model (developed by the BWRCTC) and the AlamoSim model are daily simulation models used to evaluate operational alternatives for the Bill Williams

River corridor. The models simulate operation of Alamo reservoir for different operating rules based on the historical record of daily inflows (almost 68 years). The AlamoSim model and the HEC-5 model were tested to demonstrate that they produce similar results using the same inputs.

ANALYSIS AND INTERPRETATION

Mathematical models of reservoir systems produce large amounts of data. In "raw" form, the results reveal little meaning. To compare performance differences between alternative operating strategies, some method of organizing and displaying the data is needed.

Performance Indicators and Indices

A commonly used method to distill model results for evaluating performance differences is through performance indicators and indices. Indicators serve to summarize and simplify large complex data sets. Indicators can be combined to create indices to communicate information from a broader perspective. A treatise on environmental indices (Ott 1978) defines indicators and indices as follows:

- An indicator refers to a single quantity derived from one variable or parameter used to reflect some performance attribute (e.g. the *number of days* that flow at point *X* exceeds 25 cfs).
- An index is a single number derived from two or more indicators.

Another useful method is a collection of several indicators presented at the same time to portray performance conditions (but not aggregated together). This collection of indicators is called a “performance profile”. These definitions are used throughout this discussion.

The task of defining indicators and indices is one of the most challenging aspects of analyzing technical data. Establishing performance criteria for comparing modeled alternatives is crucial to the technical success and policy usefulness of a modeling study. Obviously, if the indicators chosen do not accurately reflect how the objective (such as riparian health) responds to reservoir operation, then the conclusions drawn from the indicators will not be correct. As mentioned before, these relationships between reservoir operation and ecosystem response are highly uncertain.

Performance Profiles

During the BWRCTC technical studies, performance for each alternative was measured by a performance profile of indicators for each operating purpose such as riparian, fisheries and recreation (Table 3.1). The performance profiles were identified by the subcommittees involved in the BWRCTC based on how reservoir operation (storage and releases) affects the different operational objectives.

Discrete vs. Continuous Indicators

Performance indicators often are based on discrete numerical ranges. However, it is important to recognize that if performance indicators are the only method used to evaluate data they can result in misleading interpretations with numerical models. Extra care should be used with criteria based on a range of discrete values such as RE4 (percent of time the water surface elevation is between 1,115 and 1,125 feet). For instance, when.

Table 3.1 BWRCTC Profile of Performance Indicators

Indicator	Description
	Riparian Profile
RA1	Percent of time stream-flows at Refuge >= 18 cfs
RA2	Percent of time Alamo water surface elevation (WSE) between 1,100 and 1,171.3 feet
RA3	Percent of time Alamo Dam releases >= 25 cfs in November through January
RA4	Percent of time Alamo Dam releases >= 40 cfs in February through April and in October
RA5	Percent of time Alamo Dam releases >= 50 cfs in May through September
RA6	Total number of occurrences that Alamo Dam releases >= 1,000 cfs seven or more consecutive days in November through February
RA7	Total number of occurrences that Alamo Dam releases >= 1,000 cfs seven or more consecutive days in March through October
	Fisheries Profile
F1	Percent of time WSE between 1,110 and 1,125 feet
F2	Percent of time in March 15 through May 31 WSE fluctuates more than 2 inches per day **
F3	Percent of time in March 15 through May 31 WSE fluctuates more than 0.5 inches per day **
F4	Maximum WSE drop in feet in June through September for the period of record **
F5	Average daily release during June through September
F6	Average daily release during October through May
F7	Percent of time stream-flows at Refuge >= 25 cfs
	Wildlife Profile
W1	Percent of time WSE at or above 1,100 feet
W2	Number of times during the year that WSE > 1,135 feet two or more consecutive days
W3	Number of times from December 1 through June 30 that WSE > 1,135 feet two or more consecutive days
	Recreation Profile
RE1	Percent of time WSE >= 1,090 feet
RE2	Percent of time WSE >= 1,094 feet
RE3	Percent of time WSE >= 1,108 feet
RE4	Percent of time WSE between 1,115 and 1,125 feet
RE5	Percent of time WSE between 1,144 and 1,154 feet
RE6	Percent of time outflow is between 300 and 7,000 cfs
RE7	Percent of time in March through May WSE between 1,115 and 1,125 feet
	Water Conservation Profile
WC1	Average annual delivery of water in acre-feet to lower Colorado River (Lake Havasu)
WC2	Average annual Alamo Reservoir evaporation in acre-feet for period **
	Flood Control Criteria
FC1	Number of days WSE > 1,171.3 feet during period of record **
FC2	Maximum percent of flood control space used during period of record **
**	Note: Gray cells indicate that lower values are preferred

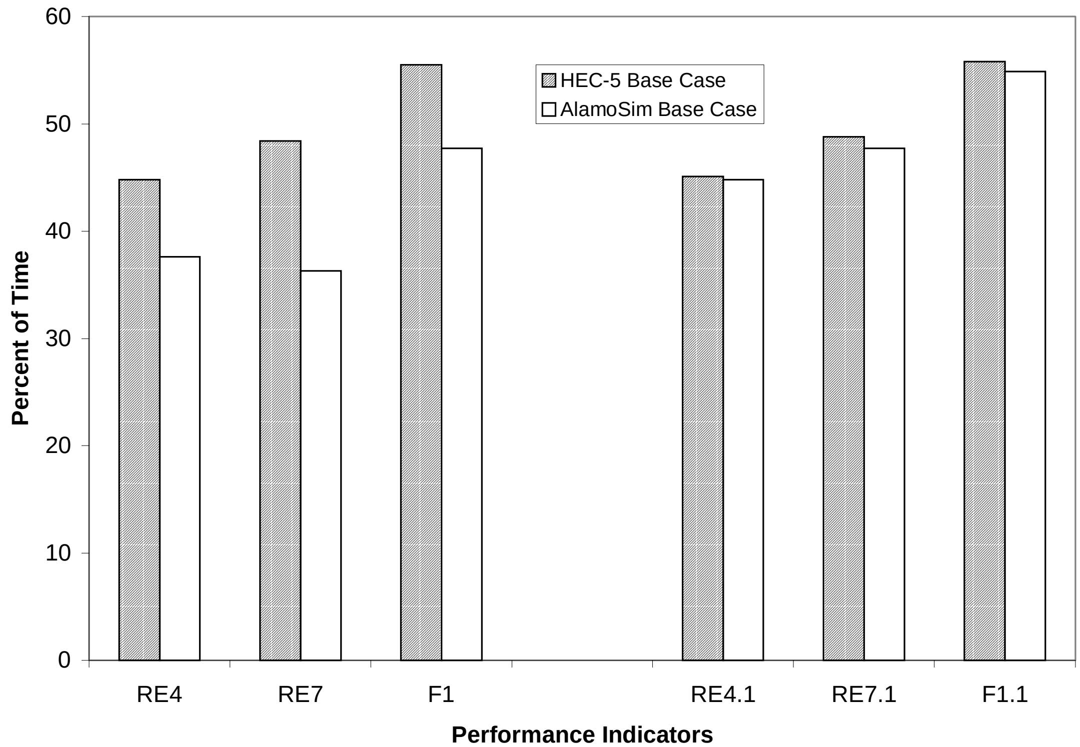

Figure 3.2 Differences in Evaluation Criteria Due to Discrete Performance Indicators

computing the value for RE4 (% of time WSE is between 1,115 and 1,125 feet), water surface elevations slightly over 1,125 (e.g. 1,125.01) are not counted

A good example of the potential problems caused by using discrete indicators was discovered when comparing AlamoSim results to HEC-5 results. During the model validation phase of this study values for RE4, RE7, and F1 for the AlamoSim Base Case were between 7% and 12% lower than for the HEC-5 Base Case. This apparent difference in performance is shown in Figure 3.2 (see RE4, RE7, and F1). Slight changes to the performance indicators largely eliminate these differences (RE4.1, RE7.1, and F1.1)

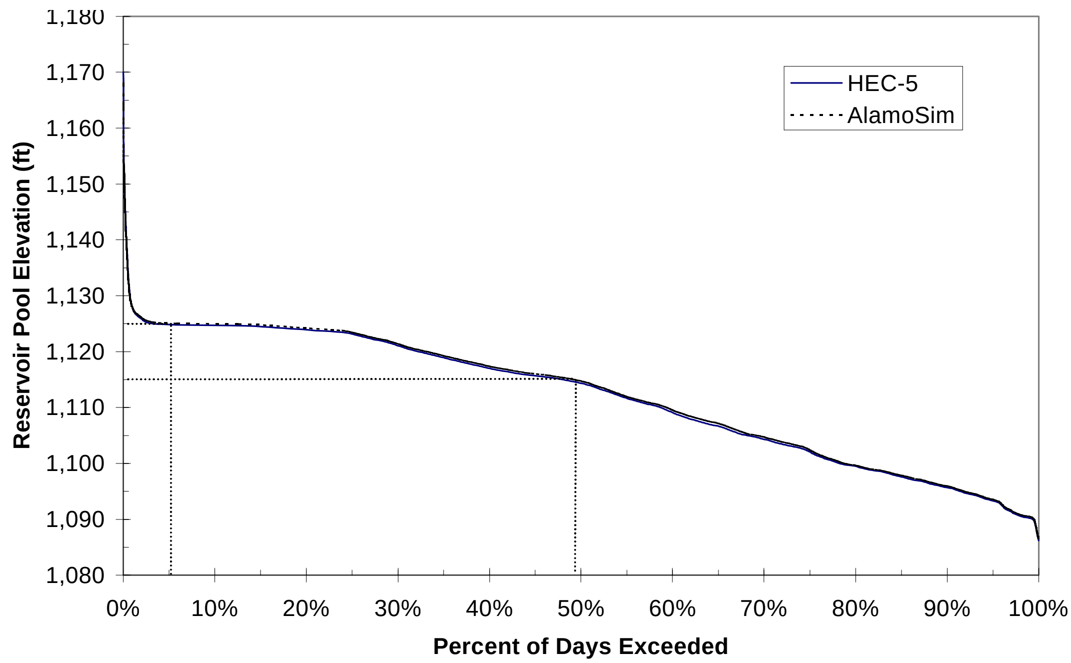

Figure 3.3 Elevation Exceedance Probabilities for HEC-5 and AlamoSim Base Case

While these performance indicators suggest substantial performance differences between the two different models, other ways of viewing the model results do not support these differences. For instance, plotting resulting reservoir water surface elevation for the two models as exceedance probabilities offers a more complete representation of reservoir operation in Figure 3.3. Note that the exceedance curves are almost identical (as expected for models designed to represent the same operating strategy). The similarity in reservoir elevation probabilities of occurrence between the models contradicts the performance differences suggested by the indicators.

These exceedance probabilities can be used to approximate values of performance indicators. In Figure 3.3, the horizontal axis represents the percent of days during the simulation period that a given elevation is exceeded. For example, estimate the value of indicator RE4 (defined as the percent of time the water surface elevation is between 1,115 ft and 1,125 ft). First, determine the percent of days during the simulation that the water surface was at or above 1,115 feet. According to Figure 3.3, the water surface elevation was at or above 1,115 feet about 49% of the days for both alternatives. Next, estimate the percent of days during the simulation that the water elevation was at or above 1,125 feet (approximately 5% of the days). Now we can estimate the percent of days the elevation is between 1,115 and 1,125 feet to be 44% (49%-5%). Compare this value to that for RE4 and RE4.1 in Table 3.2.

The water surface elevation exceedance curves demonstrate that the AlamoSim and HEC-5 models produce nearly identical results when simulating the same operating rules and input data. So why do the performance indicators (when computed using discrete values) suggest such substantial performance differences? In this case, the differences in performance indicators between models resulted from slight numerical variations in water surface elevations that do not translate to real performance differences. AlamoSim results near 1,125 were often just over 1,125 (e.g. 1,125.02 ft) and HEC-5 results near 1,125 were often just below 1,125 (e.g. 1,124.95 ft). These slight differences in elevation do not represent significant differences in actual reservoir operation, but they cause the performance indicator values to suggest apparent differences. New performance indicators for RE4, RE7 and F1 were computed using an upper range of 1125.1 ft to account for the slight differences between how the two models operate near the 1,125 ft. water surface elevation. With the new performance indicators, (designated RE4.1, RE7.1, and F1.1), all of the indicators except RA7 match within 1.9 percent between the two different models. The right side of Figure 3.2 shows values for the modified evaluation criteria labeled RE4.1, RE7.1 and F1.1.

Due to these possible misrepresentations, discrete performance reliability indicators should be supplemented with probability distributions. For this study, a post-processing program was written to compute exceedance probabilities for storage, elevation and flow. Probability information (such as exceedance probabilities) complements performance indicators and profiles by offering a more complete picture of performance. An example of additional information contained in the probability distributions is seen in Figure 3.3. As stated above, RE4 indicates that the water surface elevation is between 1,115 feet and 1,125 feet for almost 45% of the days during the simulation. However, RE4 does not communicate the fact that for 15% of the days simulated the water surface was between 1,124.5 feet and 1,125 feet, as is easily seen on the exceedance curve in Figure 3.3. Figure 3.3 also shows that for two percent of the days simulated, the water level is only inches above 1,125 feet.

Comparing Modeled Alternatives

Evaluating performance based on the profile of 28 performance indicators defined by the BWRCTC can be cumbersome when considering numerous alternatives. As an example, Table 3.2 describes several of the modeling alternatives considered as part of the Alamo study (USACE 1998). These modeled alternatives can be compared using the profile of indicators as shown in Table 3.3. However, while it is possible to compare performance of each alternative indicator by indicator, it is difficult to determine if one alternative is clearly superior to others overall. Comparing the profiles graphically can help (Figure 3.4) but it is difficult to compare more than two alternatives at one time. One way to simplify comparison of many alternatives with large numbers of indicators is to combine indicators in a meaningful way to form an index or indexes.

Table 3.2 Description of Alternative Operating Plan

Alternative	Description
GDM Plan	Originally authorized operating plan from the General Design Memorandum (represents current operation)
Base Case	The alternative used to compare AlamoSim results to HEC-5 results as discussed in Chapter 2. Based on BWRCTC alternative A1125WOD
Updated Base Case	The Base Case with the updated hydrologic record
Updated Base Case - PFE	The Updated Base Case with an additional component referred to as a "Pulse Flow Extender" (PFE). The PFE extends flows greater than or equal to 1,000 cfs for at least seven consecutive days if they occur during January through May.
OBA 2A	Operating rule based on analysis of HEC-PRM results that sets releases to maintain a target storage level. The release decision is based on deviation from target storage and the inflow
OBA 3A	Similar to OBA 2A except allows more deviation below target storage before reducing releases
OBA 3C	Similar to OBA 3A except allows even more deviation before target storage before reducing releases, and uses a less aggressive release scheme when the reservoir is below target storage but is rising
OBA 3G	A simplified version of OBA 3A allowing even more deviation below target storage before reducing releases and has the PFE component described above

Performance Index

For the Alamo study, storage and flow based performance indexes were defined as a simple visual tool to assess overall performance. These indexes represent all of the evaluation criteria in a simple two-dimensional form, based on whether the indicators are storage or flow related (see Table 3.4). These indexes can be plotted for each alternative to get a quick indication of their performance relative to one another.

Table 3.3 Alternative Performance Comparison Using Indicator Profiles

	Alternative				
Criteria	GDM Plan	Updated Base Case	OBA 2A	OBA 3G	Updated Base Case - PFE
RE1 (%)	2.8	99.5	100.0	99.5	99.5
RE2 (%)	2.4	95.7	100.0	95.3	95.4
RE3 (%)	1.8	66.2	98.7	65.7	65.8
RE4.1 (%)	0.4	46.4	83.4	47.6	45.9
RE5 (%)	0.3	0.2	0.1	0.1	0.2
RE6 (%)	6.7	3.3	3.7	2.7	3.3
RE7.1 (%)	0.9	48.3	84.8	51.6	48.7
WC1 (af)	65,327	52,689	53,954	52,802	52,728
WC2 (af)	5,857	16,997	18,876	16,949	16,971
FC1 (#)	16	0	0	0	0
FC2 (%)	13.8	0.0	0.0	0.0	0.0
W1 (%)	2.1	80.5	100.0	80.4	80.4
W2 (#)	3	14	14	13	14
W3 (#)	3	13	13	12	13
F1.1 (%)	0.7	58.3	94.7	59.4	57.7
F2 (%)	13.1	4.3	3.2	3.2	4.5
F3 (%)	42.6	26.6	7.0	25.1	26.7
F4 (ft)	67	8.1	4.2	8.1	8.1
F5 (cfs)	48	56	37.0	56.0	56.0
F6 (cfs)	171	143	148	144.0	144.0
F7 (%)	24.9	15.6	13.4	14.8	15.5
RA1 (%)	30.7	50.7	22.4	49.5	50.4
RA2 (%)	2.1	80.5	100.0	80.4	80.4
RA3 (%)	15.2	78.0	19.1	78.0	78.0
RA4 (%)	22.9	81.8	29.9	81.7	81.8
RA5 (%)	9.3	80.9	11.3	80.6	80.6
RA6 (%)	17	16	12	22	22
RA7 (%)	26	16	14	23	22

Note: Gray cells indicate that lower values are preferred.

RE1 - % of time WSE at or above 1090'
RE2 - % of time WSE at or above 1094'
RE3 - % of time WSE at or above 1108'
RE4 - % of time WSE between 1115' and 1125'
RE4.1 - % of time WSE between 1115' and 1125.1'
RE5 - % of time WSE between 1144' and 1154'
RE6 - % of time Outflow between 300 and 7,000 cfs
RE7 - % of time in March thru May WSE between 1115' and 1125'
RE7.1 - % of time in March thru May WSE between 1115' and 1125.1'
WC1 - Avg annual delivery of water to Lake Havasu
WC2 - Avg. annual evaporation in ac-ft for simulation period
FC1 - No. of days WSE above 1171.3' during simulation period
FC2 - Max percent of flood control space used during simulation period
W1- % of time WSE at or above 1100'
W2- No. of times during the year that WSE exceeds 1135' two or more consecutive days
W3 - No. of times from 1 Dec thru 30 Jun that WSE exceeds 1135' two or more consecutive days

F1 - % of time WSE between 1110' and 1125'
F1.1 - % of time WSE between 1110' and 1125.1'
F2 - % of time in Mar thru May WSE fluctuates more than 2" per day
F3 - % of time in 15 Mar thru May WSE fluctuates more than 0.5" per day
F4 - Max WSE drop, in feet, in Jun thru Sep for simulation period
F5 - Avg. Daily release during Jun thru Sep
F6 - Avg. Daily release during Oct thru May
F7 - % of time stream flows at BW Refuge equal or exceed 25 cfs
RA1 - % of time stream flows at BW Refuge equal or exceed 18 cfs
RA2 - % of time WSE between 1100' and 1171.3'
RA3 - % of time Alamo releases >= 25 cfs in Nov thru Jan
RA4 - % of time Alamo releases >= 40 cfs in Feb thru Apr and Oct
RA5 - % of time Alamo releases >= 50 cfs in May thru Sep
RA6 - Total no. of occurrences that Alamo releases >= 1,000 cfs seven or more consecutive days in Nov thru Feb
RA7 - Total no. of occurrences that Alamo releases >= 1,000 cfs seven or more consecutive days in Mar thru Oct

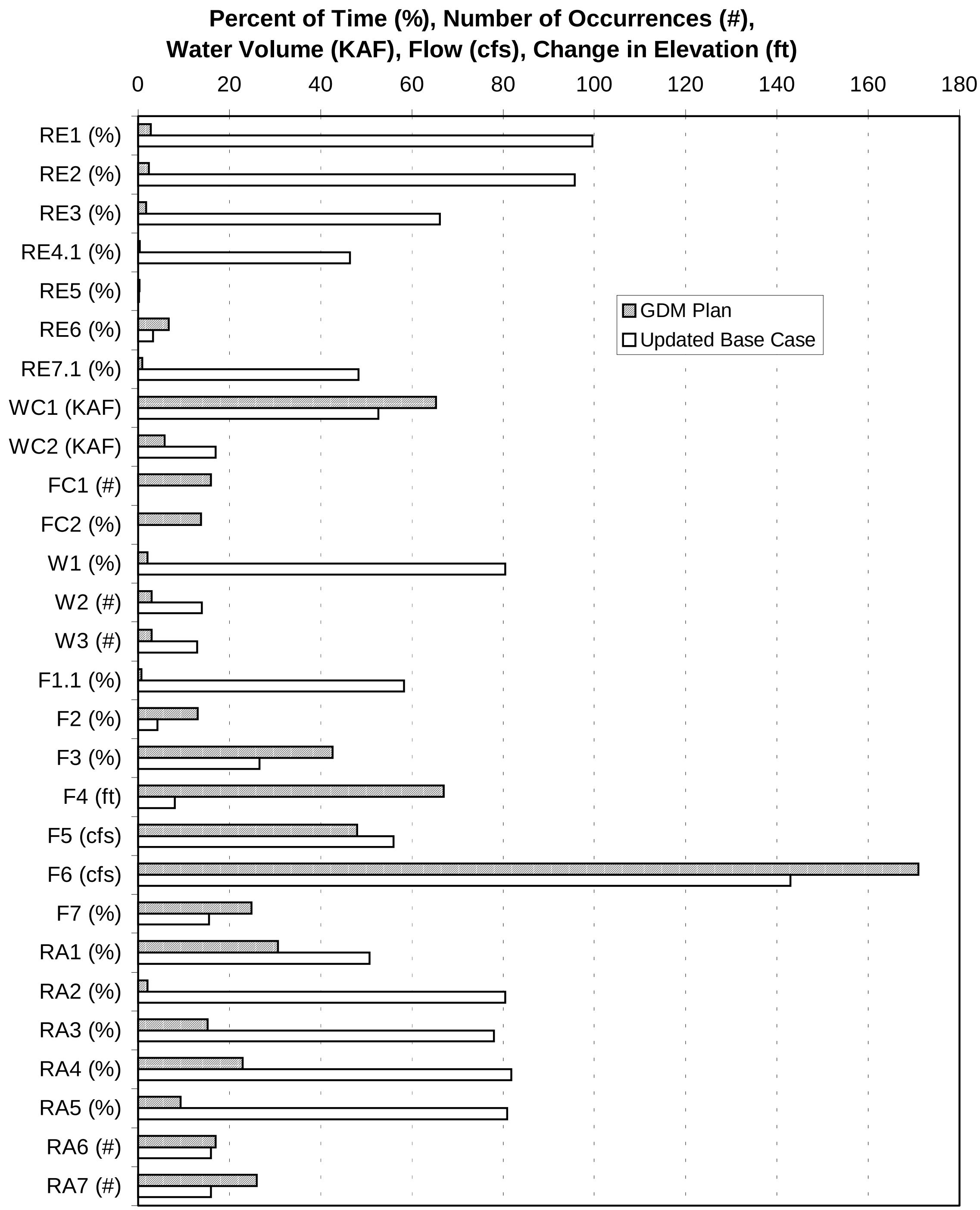

Figure 3.4 Indicator Profiles: GDM Plan vs Updated Base Case

Table 3.4 Storage and Flow Performance Index Components

Evaluation Criteria in Storage Index		Evaluation Criteria in Flow Index	
RE1	Percent of time WSE at or above 1090'	RE6	Percent of time outflow is between 300 and 7,000 cfs
RE2	Percent of time WSE at or above 1094'	WC1	Average annual delivery of water to LCR (Lake Havasu)
RE3	Percent of time WSE at or above 1108'	WC2	Average annual evaporation in acre feet for period
RE4.1	Percent of time WSE between 1115' and 1125.1'	F5	Average daily release during June thru Sept
RE5	Percent of time WSE between 1144' and 1154'	F6	Average daily release during October thru May
RE7.1	Percent of time in March thru May WSE between 1115' and 1125'	F7	Percent of time stream-flows at BW Refuge equal or exceed 25 cfs
FC1	Number of days WSE above 1171.3' during period of record	RA1	Percent of time stream-flows at BW Refuge equal or exceed 18 cfs
FC2	Maximum percent of flood control space used during period of record.	RA3	Percent of time Alamo releases >= 25 cfs in Nov. thru Jan.
W1	Percent of time WSE at or above 1100'	RA4	Percent of time Alamo releases >= 40 cfs in Feb. thru Apr. & Oct.
W2	Number of times during the year that WSE exceeds elevation 1135' two or more consecutive days	RA5	Percent of time Alamo Releases >= 50 cfs in May thru Sep.
W3	Number of times from 1 December through 30 June that WSE exceeds elevation 1135' two or more consecutive days	RA6	Total number of occurrences that Alamo releases >= 1,000 cfs seven or more consecutive days in Nov. thru Feb.
F1*	Percent of time WSE between 1110' and 1125.1'	RA7	Total number of occurrences that Alamo releases >= 1,000 cfs seven or more consecutive days in Mar. thru Oct.
F2	Percent of time in March thru May WSE fluctuates more than 2" per day		
F3	Percent of time in March 15 thru May WSE fluctuates more than 0.5" per day		
F4	Maximum WSE drop, in feet, in June thru Sept. for the period of record		
RA2	Percent of time WSE between 1100' and 1171.3'		

The performance indexes are computed using a series of simple steps. For each evaluation criteria:

- select the best and worst value for each evaluation criteria (from among the alternatives being compared)
- set the best value of the evaluation criteria to a scaled value of one (1) for that evaluation criteria

- set the worst value of the evaluation criteria to a scaled value of zero (0) for that evaluation criteria
- for evaluation criteria values between the best and worst, set their scaled values between zero and one using the simple linear transformation:

$$0 \leq \frac{Z - Z_*}{Z^* - Z_*} \leq 1$$

Where Z^* is the best criteria value and Z_* is the worst.

Once all of the individual indicator values have been scaled for the alternatives being considered:

- compute the Storage Performance Index value by averaging the individual scaled values for the evaluation criteria designated as part of the Storage Performance Index (see Table 3.1)
- compute the Flow Performance Index value by averaging the individual scaled values for the evaluation criteria designated as part of the Flow Performance Index (see Table 3.1)

This approach assumes:

1. All criteria are equally important
2. Utility is a linear function of the indicator value

For example, the best value (among the alternatives being compared) for indicator F5 [1] would be scaled to one and the worst value for F5 would be scaled to zero. The remaining values for F5 are scaled between zero and one, according to how they compare to the best and worst values. The storage and flow index values are computed by averaging the scaled values for all components in the index. If one alternative had the best values for all evaluation criteria among the alternatives being considered, it would have index values of (1,1) and would plot at the upper right-hand corner.

What information do the performance indexes offer? How can the results be interpreted? The performance indexes provide a quick visual indication of how alternatives compare relative to one another for all indicators. The way the performance indexes are computed assumes that all indicators are equally important in determining the merit of each alternative. This may or may not be an adequate representation, depending on the perspective of the interested party evaluating different alternative performances.

Given the assumptions regarding equally important consideration of all indicators, alternatives that plot further up and to the right of the other alternatives perform better overall. The plotting position of the alternatives' performance indexes should be viewed as an *ordinal* comparison, meaning that alternatives plotting further up and to the right satisfy the collective evaluation criteria better than alternatives that plot lower and to the left, but the plotting position does not provide quantitative information regarding the difference in performance. The "raw" values of the indicators should be used to make judgements regarding how much better one alternative performs than another, since the assumption of linear utility may not hold.

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[1] F5 = Avg. daily release for June - Sept. and is part of the Flow Performance Index

The indicator profiles for a group of alternatives were used to compute the storage and flow related indexes. These index values are plotted in Figure 3.5, with the Storage Performance Index along the horizontal axis and the Flow Performance Index along the vertical axis.

According to the index values in Figure 3.5, the GDM plan has the worst storage performance index value. This result suggests that the GDM plan has the worst performance on several of the individual storage related evaluation criteria, but says nothing about how different the performance is between the best and worst evaluation criteria values. The individual indicator values can be compared to determine how different the performance levels are between the GDM Plan and other alternatives.

Figure 3.4 displays the performance indicator values for the GDM Plan and the Updated Base Case. As seen in Figure 3.4, the GDM Plan's performance for recreation objectives is dismal compared to the Updated Base Case. The GDM Plan performs much worse for five of the seven recreation evaluation criteria and only slightly better for one (RE6). Similar results are seen for fisheries and riparian objectives. The only objectives for which the GDM Plan performs better is water conservation, and for W2 and W3 (indication of high water levels potentially harmful to eagle nesting).

According to Figure 3.5 the first optimization-based alternative, OBA 2A, has the best storage performance index value, but the worst flow index value. The performance index values suggests that the optimization based rule form is very successful at satisfying indicators related to storage, but not very effective in satisfying flow related indicators.

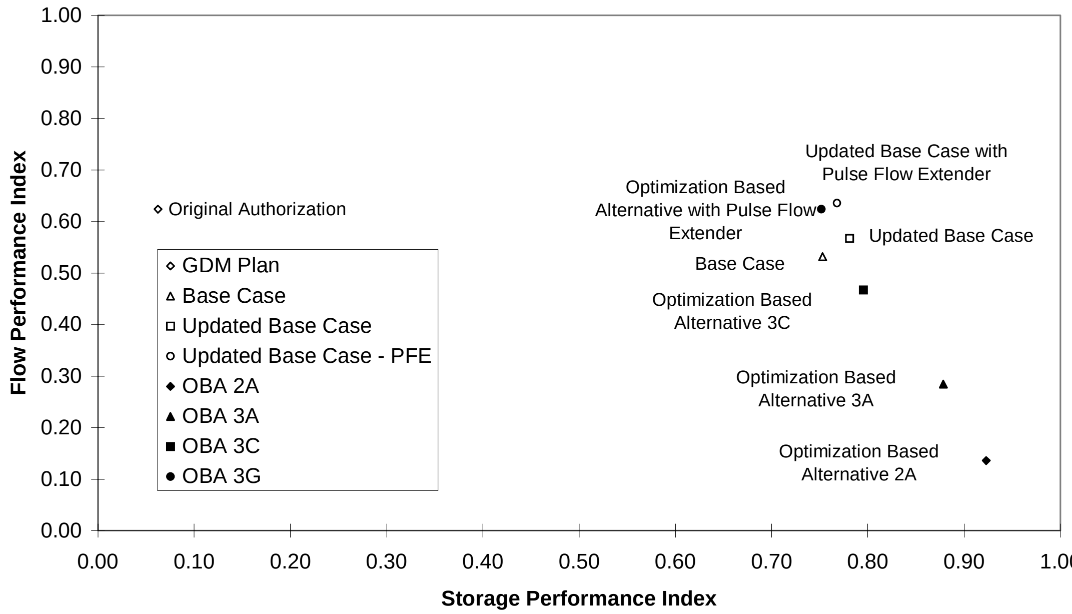

Figure 3.5 Performance Index Comparisons for Multiple Alternatives

Summary

Models of complex systems require some form of simplification to evaluate tradeoffs between different modeled alternatives. Indicators and indexes can be effective ways to evaluate different alternatives if their weaknesses are recognized and compensated for.

QUANTIFYING TRADEOFFS FOR BALANCING CONFLICTS

The people asked to find an operating strategy for Alamo Dam that would reduce conflicts felt that they needed to understand the trade-offs associated with operating for different objectives. A particularly challenging aspect was to balance conflict between different endangered species. The Corps personnel recognized that operating to prevent inundation of eagle nests could likely impair the downstream riparian habitat indicators and their associated obligate species. However, the BWRCTC study for the *Proposed*

Water Management Plan (1994) did not attempt to quantify these tradeoffs. This study evaluates strategic operation policies to reduce or prevent bald eagle nest inundation and harassment. The resulting impacts on the other interests, including other federally listed species dependant on the riparian corridor downstream are approximated.

History of Eagles at Alamo Reservoir

Bald eagles have been observed nesting near Alamo Reservoir since December 1986. Two pair of eagles have been returning each year. One pair, called the Alamo eagles, has nested on a tree snag within the reservoir seven out of the nine years between 1988 and 1996. Another pair, called the Ive's Wash eagles, has nested on a snag within the reservoir two out of ten years between 1987 and 1996. The other eight years, the Ive's Wash eagles have nested on a cliff below Alamo Dam. If the eagles nest in a snag around the reservoir, the nest can be flooded by rising water levels. In addition, if the water level rises a few feet up the base of the tree, boaters approaching the nest can be considered harassment under the Endangered Species Act. The eagles typically build their nests in the fall (October to December) after the dry summer months when the lake tends to be low. Historically, when the eagles have selected a snag, the reservoir water surface has been at the base of the tree or lower.

Modeling Eagle Nesting

According to data provided by Greg Beatty, Acting Nonpasserine Birds Program Manager, Arizona Game and Fish Department, the nest sites chosen between 1987 and 1996 were between elevations 1,135 and 1,138 feet. Data for one of the nests shows that the base of the nest is approximately 22 feet above the ground. This means that the base of the tree is somewhere between 1,113 and 1,116 feet. According to Mr. Beatty, the eagles built a nest at the beginning of the 1997 breeding season in a willow snag, five to ten feet lower than previous nests, and about 200 feet west of the previous nest sites. There are numerous snags around the lake, and the exact elevations of possible nesting sites are not known.

To simulate the interaction of eagle nesting and reservoir operation, several assumptions were made:

- The Alamo eagles have a 0.778 probability of using a nesting site within the reservoir, based on historical pattern of 7 out of 9 years.
- The Ive's Wash eagles have a 0.20 probability of using a nesting site within the reservoir, based on historical pattern of 2 out of 10 years.
- Both pairs of eagles could nest within the reservoir in any given year.
- Eagles can choose a nesting site elevation between 1,125 feet and 1,138 feet based on available snags.
- Both pairs of eagles will choose their nesting site and the elevation will be known by November 1 of each year.
- Eagles will not build a nest closer than fifteen feet to the surface of the water surface on November 1. (This means the valid nesting elevation range will be reduced if the reservoir water surface is above 1,110 feet.)
- Harassment occurs, due to boat accessibility, at water surface elevation 1,115 feet.
- Eagle young normally fledge by late May, but often remain in the nest through July.

The AlamoSim model includes a probabilistic simulation component that simulates the nesting location of each eagle pair on November 1 based on the above frequencies. This simulation approach consists of using a statistical sampling technique to represent stochastic inputs, and applying these inputs to a model to determine the resulting outputs. This approach is a form of Monte Carlo simulation (Hammersly and Handscomb 1965; Kalos and Whitlock 1986). If either of the eagles is simulated to nest within the reservoir, a nest elevation is selected from the available nesting site range. The available nesting site range is represented as a uniform distribution between 1,125 and 1,138 feet, modified by the reservoir water surface elevation. For example, if the water surface elevation is 1,112.5 feet on November 1, the available nesting site range would be 1,127.5 to 1,138 feet. (The lower range is determined by adding 15 feet to the water surface elevation of 1,112.5 feet.) Using this technique, if the reservoir is high enough on November 1, there could be no available nesting sites on the reservoir for that year.

An additional post processing routine was developed to quantify impacts on the eagle nests. The eagle data post processor summarizes:

- the nest elevations for each year a nest is within the reservoir,
- the number of days the water surface elevation exceeds 1,115 feet when a nest is within the reservoir (representing a nuisance),
- the number of days the water surface elevation is within 5 feet of the nest,
- and the number of days the water surface elevation equals or exceeds the elevation of the nest.

The post processor also keeps track of the number of inundation events. An inundation event occurs if the reservoir pool elevation reaches the nest elevation during the nesting season. Once a nest is inundated, the nest is abandoned. Under these assumptions, there can never be more than two inundation events in a given year, (a maximum of one per nest per year). All of this data is computed for the period November to July and December to May.

Monte Carlo Methods

Monte Carlo methods or techniques involve the use of probabilistic methods or games of chance to solve problems. Historically, the term Monte Carlo Method was used to describe procedures for solving non probabilistic-type problems by using probabilistic-type methods. An example of this type of application is to use a game of chance (throwing darts) to approximate the answer to a definite integral (Farlow 1993). More recently, the term Monte Carlo analysis has been used to describe computer-based methods of analysis that uses statistical sampling techniques to obtain a probabilistic approximation to the solution of a mathematical equation or model (EPA 1997; Rubinstein 1981).

In most simulation applications, the basic goal of Monte Carlo analysis is to characterize the uncertainty and variability in estimates of some stochastically influenced event. There are essentially three major decisions necessary to perform Monte Carlo analysis:

- Selection of development of conceptual and mathematical models of the process being studied

- Selection of input data and probability distributions for use in generating random samples
- Select random number sampling technique

The conceptual and mathematical model(s) should be developed considering all physical and causal mechanisms likely to influence the process being studied, with explicit consideration of pathways of uncertainty or variability. In this study, the mathematical model used is the reservoir operating rules and mass balance. One variable factor is the location and elevation of potential eagle nests each year.

The observed data available should be evaluated to select a probability distribution function that adequately represents the existing state of knowledge for the random variable in question. The EPA's *Guiding Principles for Monte Carlo Analysis* (1997) provides a series of questions an analyst can ask to help select a distributional shape. For this study, the uniform distribution was selected to be the most representative of the observed historical nesting patterns.

Two sampling techniques are most often used for Monte Carlo Analysis: simple random sampling and Latin Hypercube sampling. Latin Hypercube sampling is a form of stratified sampling techniques that have been shown to ensure that upper and lower ends of distributions used are well represented. Furthermore, the stratified sampling technique is more efficient than simple random sampling, thus requiring fewer simulations to produce the same level of precision. Latin Hypercube sampling is generally recommended over simple random sampling when using complex models. For this study, simple random sampling was used since the uniform distribution was selected, and the computational times for the model runs were not prohibitive.

Considering the Threat of Inundation

The probability of the eagles being affected by rising lake levels is subject to the elevation at which the eagles nest, the storage of the reservoir at the beginning of the nesting season, the inflows during the nesting season, the operating strategy, and the physical constraints on release capacity. To evaluate possible operating strategies to try and prevent negative impacts to eagle nesting due to rising lake levels, some tests were done to characterize the possibility of protection. Four of the largest flood events from the historical record of daily inflows were used to determine the largest net increase in storage that would occur based on inflow and release capacity. The following events were used:

Start Date	End Date	Maximum Increase in Storage (acre-ft)
12/01/1940	5/31/1941	58,700
1/1/1978	4/30/1978	146,600
1/10/1980	3/31/1980	202,900
1/1/1993	3/22/1993	115,500

One of the events (1980) would cause water levels to encroach well into the range of nesting elevations *even if the reservoir were completely empty* at the beginning of the floods and maximum releases were made during the floods. This simple analysis demonstrates that the eagle nests cannot be protected 100 % of the time without structural modifications to the dam outlet works.

Another analysis was done to gain a better understanding of possible maximum reservoir levels between November 1 and July 31. AlamoSim was modified to simulate operation using optimization based alternative 3G (OBA 3G) from November 1 to July 31, starting over each year from a specified storage level. Results from this analysis show the maximum reservoir levels that would occur when starting from a given reservoir pool level on November 1 and operating according to alternative OBA 3G. Simulations were run for November 1 starting elevations of 1100, 1105, 1110, 1115, and 1120 feet. Figure 3.6 shows the traces of reservoir pool elevations between November 1 and July 31 for the 68 years of inflow with a starting pool elevation of 1,100 feet. Figure 3.7 shows the 68 traces for a starting pool elevation of 1,120 feet. Note that under both starting conditions, numerous traces of water levels reach or exceed the potential nesting elevations (1,125 – 1,138 feet). Information contained in these multiple event traces was summarized by computing the maximum reservoir pool elevation exceedance probabilities for the different starting elevations. Figure 3.8 describes the probability (X) that the maximum reservoir elevation between November 1 and July 31 for a single year will not exceed some value (Y) given a starting elevation of 1100, 1105, 1110, 1115 or 1120 feet. These curves provide the following types of information:

> If the reservoir pool elevation in Alamo this November 1 is 1,100 feet, there is a 0.75 probability that the reservoir pool elevation will not exceed 1,125 feet before July 31, and a 0.93 probability that it will not exceed 1,138 feet. Conversely, there is a 25% chance that the elevation will exceed 1,125 feet and a 7% chance that it will exceed 1,138 feet between November 1 and July 31.
>
> If the reservoir pool elevation is 1,120 feet on this November 1, there is a 0.57 probability that the reservoir pool elevation will not exceed 1,125 feet before July 31, and a 0.87 probability that it will not exceed 1,138 feet. This means that if the reservoir level is at 1,120 feet on November 1 and an eagle nest is occupied then there is at least a 13% chance that it will be inundated if no preventative measures are taken.

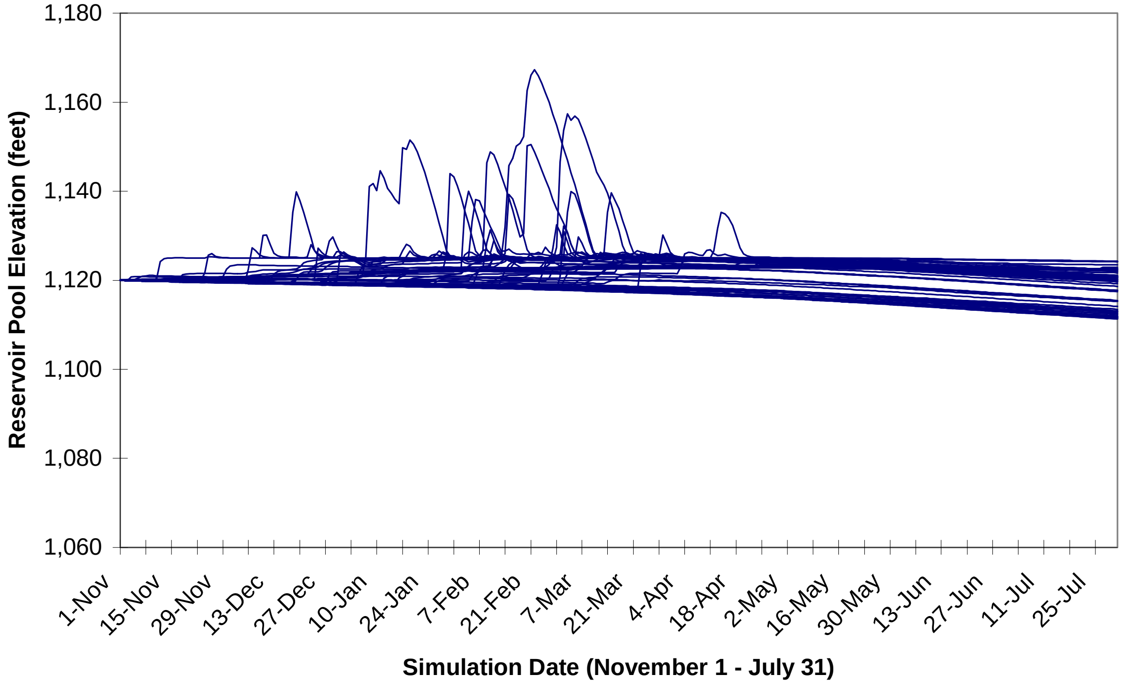

Figure 3.6 Possible Reservoir Pool Elevations Under OBA 3G Starting From 1,100 feet on November 1

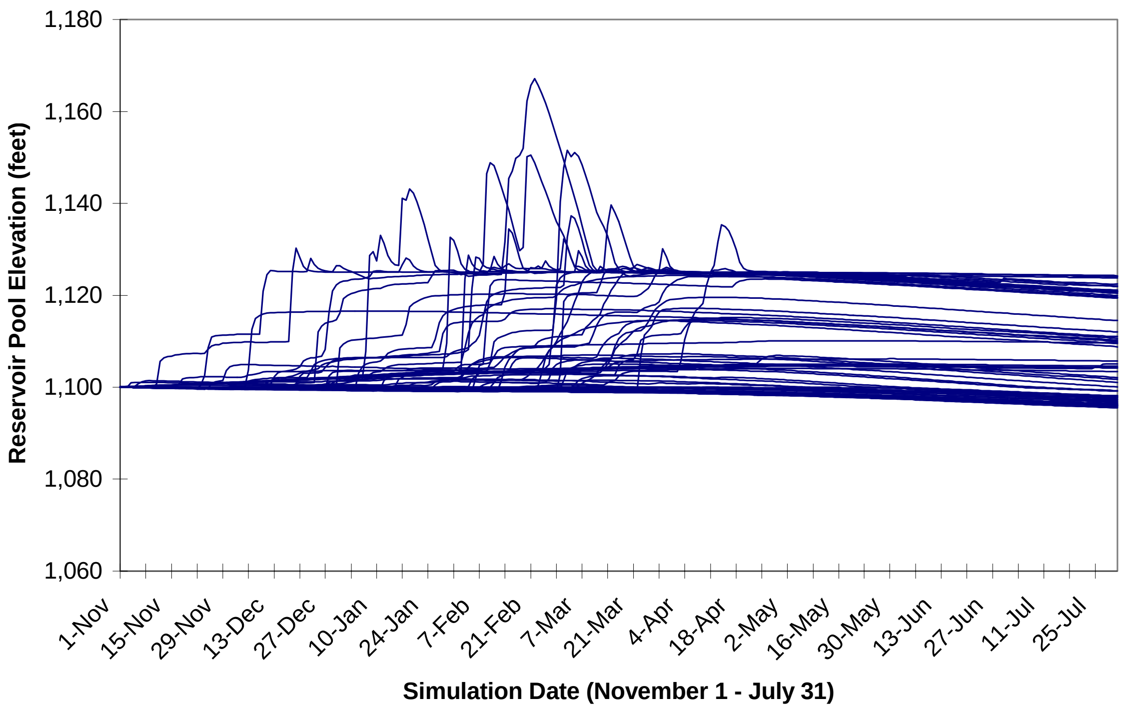

Figure 3.7 Possible Reservoir Pool Elevations Under OBA 3G Starting From 1,120 feet on November 1

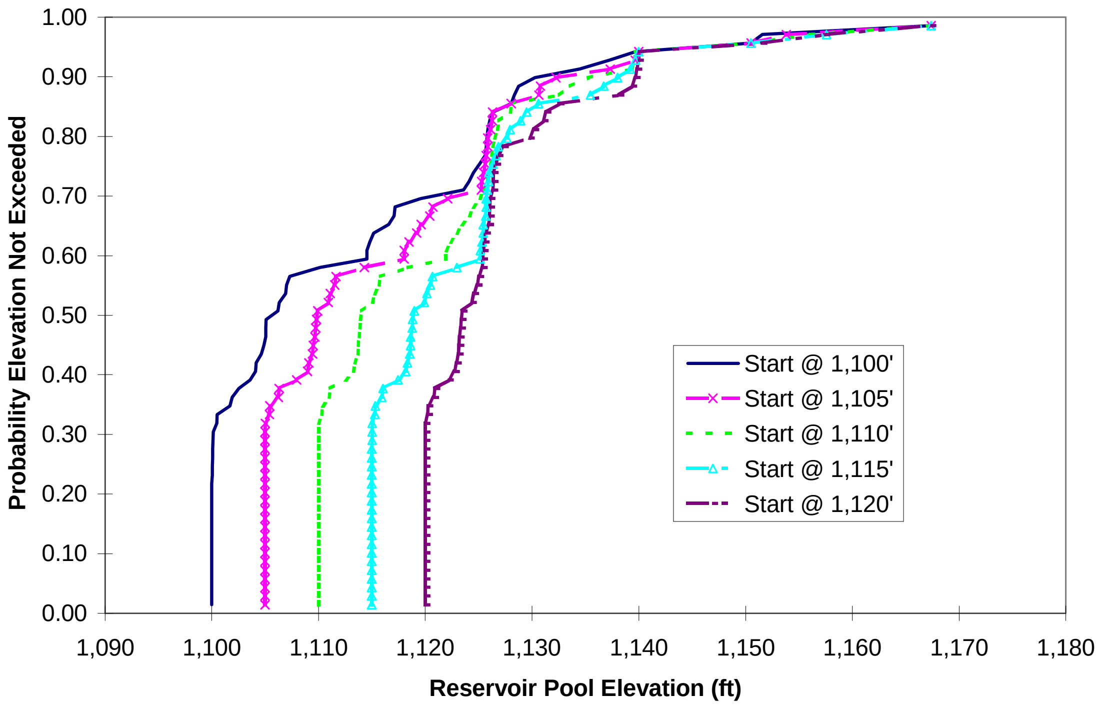

Figure 3.8 Probability of Maximum Reservoir Pool During November through July for Alternative OBA 3G for Different Starting Elevations on November 1

This position analysis (Hirsch 1978) of possible maximum reservoir pool elevations given different starting elevations demonstrates that a significant flood threat exists any time a nest is occupied within elevations of 1,125 feet and 1,138 feet.

Risks to Eagles from Previously Proposed Policies

To approximate the impact on eagle nesting caused by water surface elevations in Alamo reservoir, two previously discussed operating alternatives (Updated Base Case - PFE WD and OBA 3G WD) were tested with the eagle-nesting component in the model active. AlamoSim was run as before on a daily time step during October 1, 1928 to August 29, 1996, except instead of running the simulation once, it was run at least 200 times. The reservoir operation was the same for every simulation, but the eagle nesting elevations could change during each year of each simulation. By running the simulation many times and averaging the results, an approximation of impacts on eagle nesting is made assuming inflows in the near future are similar to those observed over the past sixty eight years. Indicators proposed to measure the impacts on the eagle nesting are shown in Table 3.5. The Optimization Based Alternative with flexible draw-down (OBA 3G WD) caused an average of 10 inundation events over sixty-eight years of operation. Therefore, the probability that a nest will be inundated in any given year is 0.147 when operating according to this operational policy. The Updated Base Case - PFE with flexible draw-down (Updated Base Case - PFE WD) resulted in an average of 12 inundation events over sixty eight years of operation and a 0.181 probability that a nest may be inundated in any year. In addition, for both alternatives, the water level is high enough to allow harassment for around 37% of the days during November through July.

If the reservoir is operated according to one of the two alternatives proposed earlier, (including a version of the BWRCTC recommended policy), an eagle nest is likely to be inundated on average every 6 or 7 years and water levels are expected to be high enough to allow harassment from boaters 37% of the time. Figure 3.9 shows the occurrence of harassment and encroachment for both the Alamo and Ive's Wash eagles during November through July according to the two alternatives tested.

Operating to Reduce the Likelihood of Nest Inundation

Since the analysis discussed above showed that eagle nest inundation could not be prevented 100% of the time, an operating policy was devised to try and achieve a 95% protection rate against eagle nest inundation. The rule form is similar to the other Optimization Based Rule forms discussed earlier. The simulation for protecting eagle nests against inundation in AlamoSim depends on the probabilistic simulation of the

Table 3.5 Impacts on Eagle Nesting Without Protecting Against Inundation

	Alternative	
Criteria	OBA 3G WD	Updated Base Case - PFE WD
IN1	10	12.2
IN2	14.7	18.0
EG1	37.3	37.0
EG2	7.82	8.24
EG3	2.10	2.24
EG4	0.55	0.81
EG5	0.14	0.23
EG6	37.6	37.3
EG7	9.2	9.8
EG8	2.4	2.7
EG9	0.83	1.2
EG10	0.20	0.34
# of Simulations	200	200

IN1 - Number of nests flooded at least once in a year
IN2 - Probability of inundation event occurring in any year (%)
EG1 - Percent of days WSE >= 1,115 during Nov thru Jul (Harassment)
EG2 - Percent of days WSE within 5 feet of Alamo eagle nest during Nov thru Jul
EG3 - Percent of days WSE within 5 feet of Ive’s Wash eagle nest during Nov thru Jul
EG4 - Percent of days WSE >= elevation of Alamo eagle nest during Nov thru Jul
EG5 - Percent of days WSE >= elevation of Ive’s Wash eagle nest during Nov thru Jul
EG6 - Percent of days WSE >= 1,115 during Dec thru May (Harassment)
EG7 - Percent of days WSE within 5 feet of Alamo eagle nest during Dec thru May
EG8 - Percent of days WSE within 5 feet of Ive’s Wash eagle nest during Dec thru May
EG9 - Percent of days WSE >= elevation of Alamo eagle nest during Dec thru May
EG10 - Percent of days WSE >= elevation of Ive’s Wash eagle nest during Dec thru May

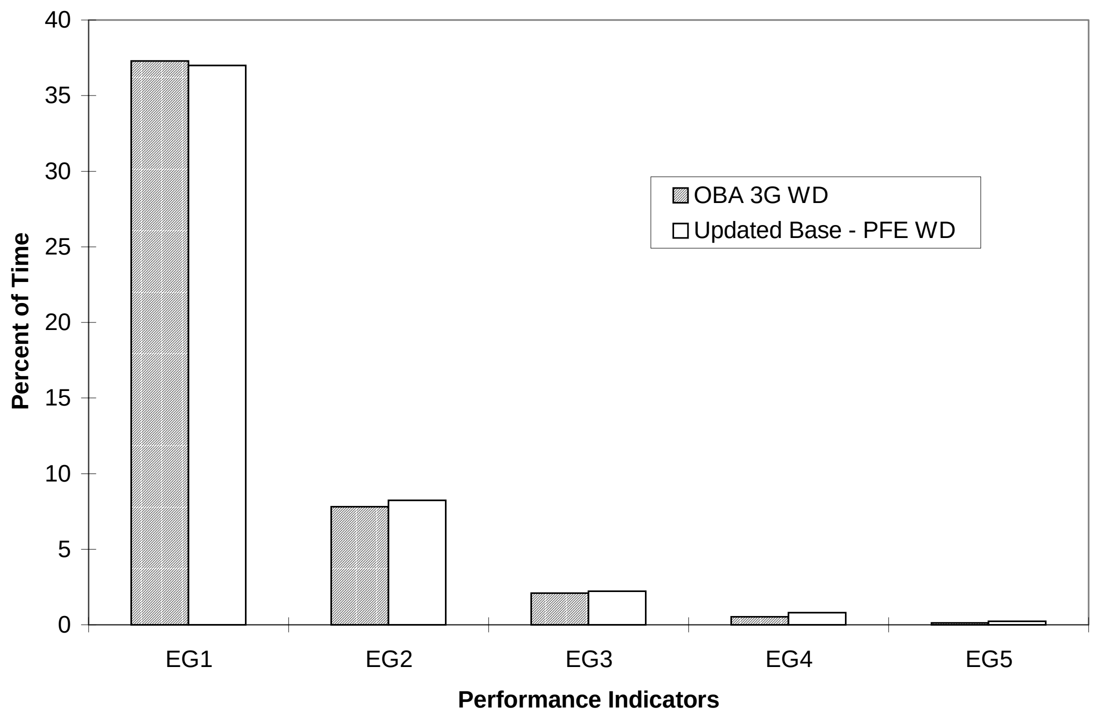

Figure 3.9 Performance Indicators for Alternatives Without Eagle Nest Protection

eagle nesting events. If one or two eagle nests are simulated to be active within the reservoir, then the eagles are said to be vulnerable. If the eagles are vulnerable, then the operational policy is switched from the "normal" policy to the protection rule. If the protection rule is invoked, it remains active from November 1 to July 31. The main difference between the protection rule and the "normal" rule is the storage target. If an eagle nest is inhabited, then the storage target is set to 101,000 acre-feet (1,107.3 feet elevation) as opposed to 160,977 acre-feet (1,125 feet elevation) used in the "normal" operation. This lower storage target provides storage space in the reservoir to contain flood events while trying to reduce the chance of inundation to 5% or less.

Two eagle protection alternatives were studied by adding the eagle protection rule component to the best two alternatives analyzed previously, (now referred to as Updated Base Case - PFE WD EP and OBA 3G WD EP, where EP indicates eagle protection).

Under the Updated Base Case - PFE WD EP, if no eagle nests are vulnerable, then the alternative uses the same operating policy as in Updated Base Case - PFE WD. If an eagle nest is vulnerable, then the eagle protection rule described above becomes the controlling operating policy. Again, the daily simulation for the period of record was run at least 200 times, with probabilistic simulation of eagle nesting each year. The results were monitored after each fifty runs to determine when the model outputs were stable. Table 3.6 contains the estimated impacts to the eagles under the two protection-oriented operating policies. Both alternatives were able to achieve slightly better than 95% protection against inundation events — 9% to 13% better than the non-protection policy. The frequency of conditions deemed to allow harassment is reduced from 37% without protection to less than 1% with protection (Figure 3.10). The protection strategies reduce, but do not eliminate risk to eagle nesting. However, these improvements for the eagles' nesting come at a price of reduced performance for other objectives.

Performance Trade-offs

As shown above, the operational strategies tested to reduce negative impacts on bald eagle nesting were successful. The frequency of inundation was reduced from 18% per year to 5% per year -- a 72% reduction. Unfortunately, this change in operation also significantly decreased performance for other objectives. Table 3.7 presents a summary of evaluation criteria values for the Updated Base Case - PFE WD and the OBA 3G alternatives with and without eagle nest protection. The performance index values shown in Figure 3.11 suggest that the alternatives with eagle protection perform worse overall for storage related criteria, and better overall for flow related criteria.

Table 3.6 Impacts on Eagle Nesting when Protecting Against Indundation

	Alternative	
Criteria	OBA 3G WD with Protection	Updated Base Case - PFE WD with Protection
IN1	3.2	3.3
IN2	4.7	4.9
EG1	0.6	0.7
EG2	0.30	0.30
EG3	0.07	0.08
EG4	0.21	0.20
EG5	0.05	0.06
EG6	0.9	0.9
EG7	0.4	0.4
EG8	0.1	0.1
EG9	0.31	0.30
EG10	0.07	0.09
# of Simulations	200	200

IN1 - Number of nests flooded at least once in a year
IN2 - Probability of inundation event occurring in any year (%)
EG1 - Percent of days WSE >= 1,115 during Nov thru Jul (Harassment)
EG2 - Percent of days WSE within 5 feet of Alamo eagle nest during Nov thru Jul
EG3 - Percent of days WSE within 5 feet of Ive's Wash eagle nest during Nov thru Jul
EG4 - Percent of days WSE >= elevation of Alamo eagle nest during Nov thru Jul
EG5 - Percent of days WSE >= elevation of Ive's Wash eagle nest during Nov thru Jul
EG6 - Percent of days WSE >= 1,115 during Dec thru May (Harassment)
EG7 - Percent of days WSE within 5 feet of Alamo eagle nest during Dec thru May
EG8 - Percent of days WSE within 5 feet of Ive's Wash eagle nest during Dec thru May
EG9 - Percent of days WSE >= elevation of Alamo eagle nest during Dec thru May
EG10 - Percent of days WSE >= elevation of Ive's Wash eagle nest during Dec thru May

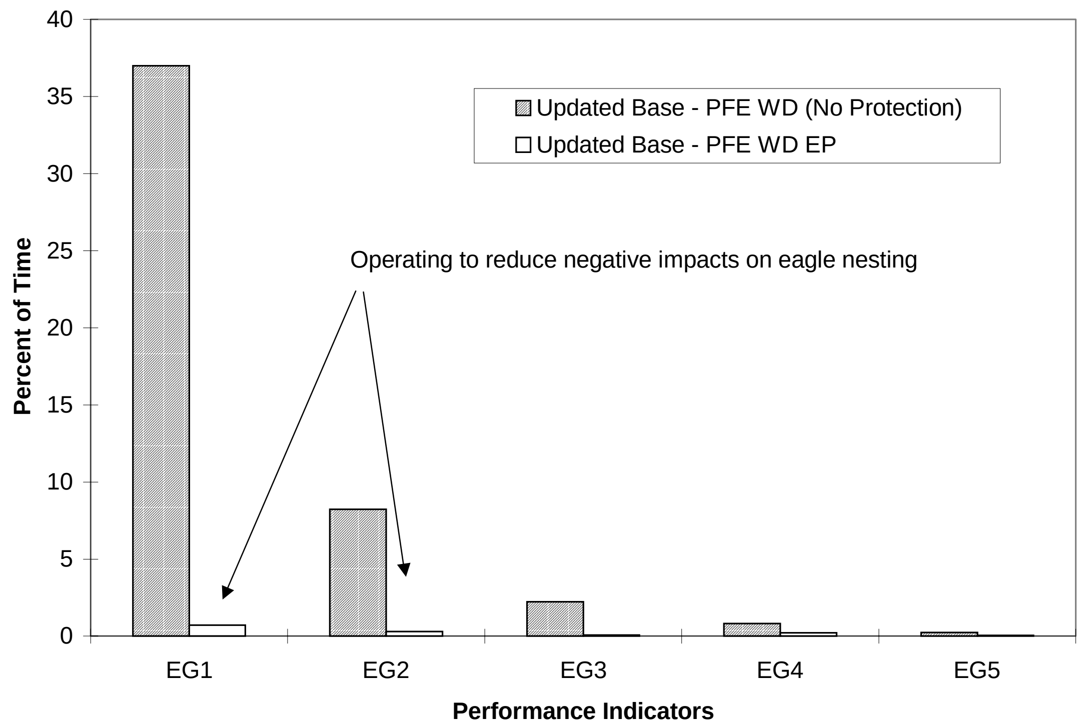

Figure 3.10 Eagle Performance Indicators: With and Without Eagle Nest Protection

Figure 3.12 offers a direct comparison of evaluation criteria values for the Updated Base Case (including the pulse flow extender and flexible draw-down rules) without eagle protection and with eagle protection. The recreation evaluation criteria values are much worse for the alternative designed to protect eagle nesting as shown in Figure 3.12. The largest recreation related decline occurs for RE3 (percent of time WSE at or above 1,108 feet), going from 60% to only 10% -- an 83% reduction in performance. The eagle protection policy does slightly better for water conservation evaluation criteria with an 8% increase in the average annual delivery to Lake Havasu and a 14% reduction in average annual evaporation from Alamo.

Results for the fishery evaluation criteria are mixed. For instance, the F2 indicator (a measure of lake fluctuation during spawning and growing season) for the

Table 3.7 Performance Indicator Profiles: With and Without Eagle Nest Protection

	Without Protection		With Protection	
Criteria	Updated Base-PFE WD	OBA 3G WD	Updated Base-PFE WD EP	OBA 3G WD EP
RE1 (%)	99.6	99.6	98.3	98.4
RE2 (%)	95.2	94.6	89.7	89.8
RE3 (%)	60.0	58.8	10.2	10.0
RE4.1 (%)	40.6	42.1	5.3	5.4
RE5 (%)	0.2	0.1	0.1	0.0
RE6 (%)	3.4	3.0	3.5	3.4
RE7.1 (%)	43.0	45.7	5.7	5.9
WC1 (af)	53,129	53,241	57,328	57,330
WC2 (af)	16,622	16,576	14,229	14,224
FC1 (#)	0	0	0	0
FC2 (%)	0.0	0.0	0.0	0.0
W1 (%)	77.8	77.5	53.4	53.6
W2 (#)	13	12	5.9	5.6
W3 (#)	12	11	5.9	5.6
F1.1 (%)	51.9	53.2	7.9	8.0
F2 (%)	5.4	4.2	3.5	3.3
F3 (%)	27.6	25.8	23.6	23.3
F4 (ft)	9.4	11.0	7.8	7.8
F5 (cfs)	58.0	59.0	40.9	41.1
F6 (cfs)	143.0	143.0	157.5	157.5
F7 (%)	15.9	15.2	17.3	17.3
RA1 (%)	49.6	48.7	35.4	35.4
RA2 (%)	77.8	77.5	53.4	53.6
RA3 (%)	73.3	73.1	41.6	41.8
RA4 (%)	79.6	79.4	56.1	56.4
RA5 (%)	78.7	78.1	57.7	57.9
RA6 (%)	21	21	23.6	24.1
RA7 (%)	25	26	26.7	25.7

Note: Gray cells indicate that lower values are preferred.

RE1 - % of time WSE at or above 1090'
RE2 - % of time WSE at or above 1094'
RE3 - % of time WSE at or above 1108'
RE4 - % of time WSE between 1115' and 1125'
RE4.1 - % of time WSE between 1115' and 1125.1'
RE5 - % of time WSE between 1144' and 1154'
RE6 - % of time Outflow between 300 and 7,000 cfs
RE7 - % of time in March thru May WSE between 1115' and 1125'
RE7.1 - % of time in March thru May WSE between 1115' and 1125.1'
WC1 - Avg annual delivery of water to Lake Havasu
WC2 - Avg. annual evaporation in ac-ft for simulation period
FC1 - No. of days WSE above 1171.3' during simulation period
FC2 - Max percent of flood control space used during simulation period
W1- % of time WSE at or above 1100'
W2- No. of times during the year that WSE exceeds 1135' two or more consecutive days
W3 - No. of times from 1 Dec thru 30 Jun that WSE exceeds 1135' two or more consecutive days
F1 - % of time WSE between 1110' and 1125'
F1.1 - % of time WSE between 1110' and 1125.1'
F2 - % of time in Mar thru May WSE fluctuates more than 2" per day
F3 - % of time in 15 Mar thru May WSE fluctuates more than 0.5" per day
F4 - Max WSE drop, in feet, in Jun thru Sep for simulation period
F5 - Avg. Daily release during Jun thru Sep
F6 - Avg. Daily release during Oct thru May
F7 - % of time stream flows at BW Refuge equal or exceed 25 cfs
RA1 - % of time stream flows at BW Refuge equal or exceed 18 cfs
RA2 - % of time WSE between 1100' and 1171.3'
RA3 - % of time Alamo releases >= 25 cfs in Nov thru Jan
RA4 - % of time Alamo releases >= 40 cfs in Feb thru Apr and Oct
RA5 - % of time Alamo releases >= 50 cfs in May thru Sep
RA6 - Total no. of occurrences that Alamo releases >= 1,000 cfs seven or more consecutive days in Nov thru Feb
RA7 - Total no. of occurrences that Alamo releases >= 1,000 cfs seven or more consecutive days in Mar thru Oct

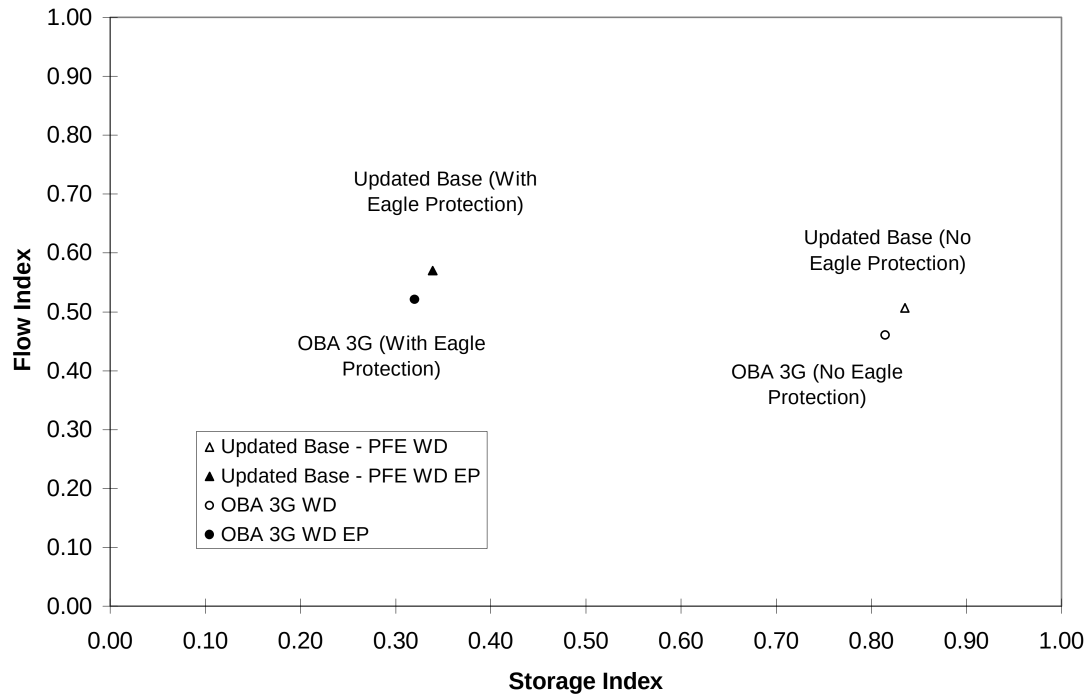

Figure 3.11 Performance Index Values for Alternatives With and Without Eagle Nest Protection

policy with eagle protection is 35% better than the policy without eagle protection. However, the value for F1.1 (a measure of how frequently the water level is within a desirable zone in the lake to support spawning and growing) is 84% lower for the protection alternative.

The eagle nest protection policy is designed to reduce the threat to the eagles' welfare posed by the reservoir, but ironically, this threat exists because the reservoir is such an attractive site to nest and raise young. The reservoir serves as the primary forage area for the eagles that nest in the basin. In a 1988 letter to the Corps, the U.S. Fish and Wildlife Service requested that Alamo Lake not be drawn down below 1,100 feet to ensure adequate forage area for the two pairs of eagles nesting near the reservoir (BWRCTC 1994). While *helping* the eagles by reducing the threat of harassment and nest inundation, the protection alternatives also *harm* the eagles by causing the lake level

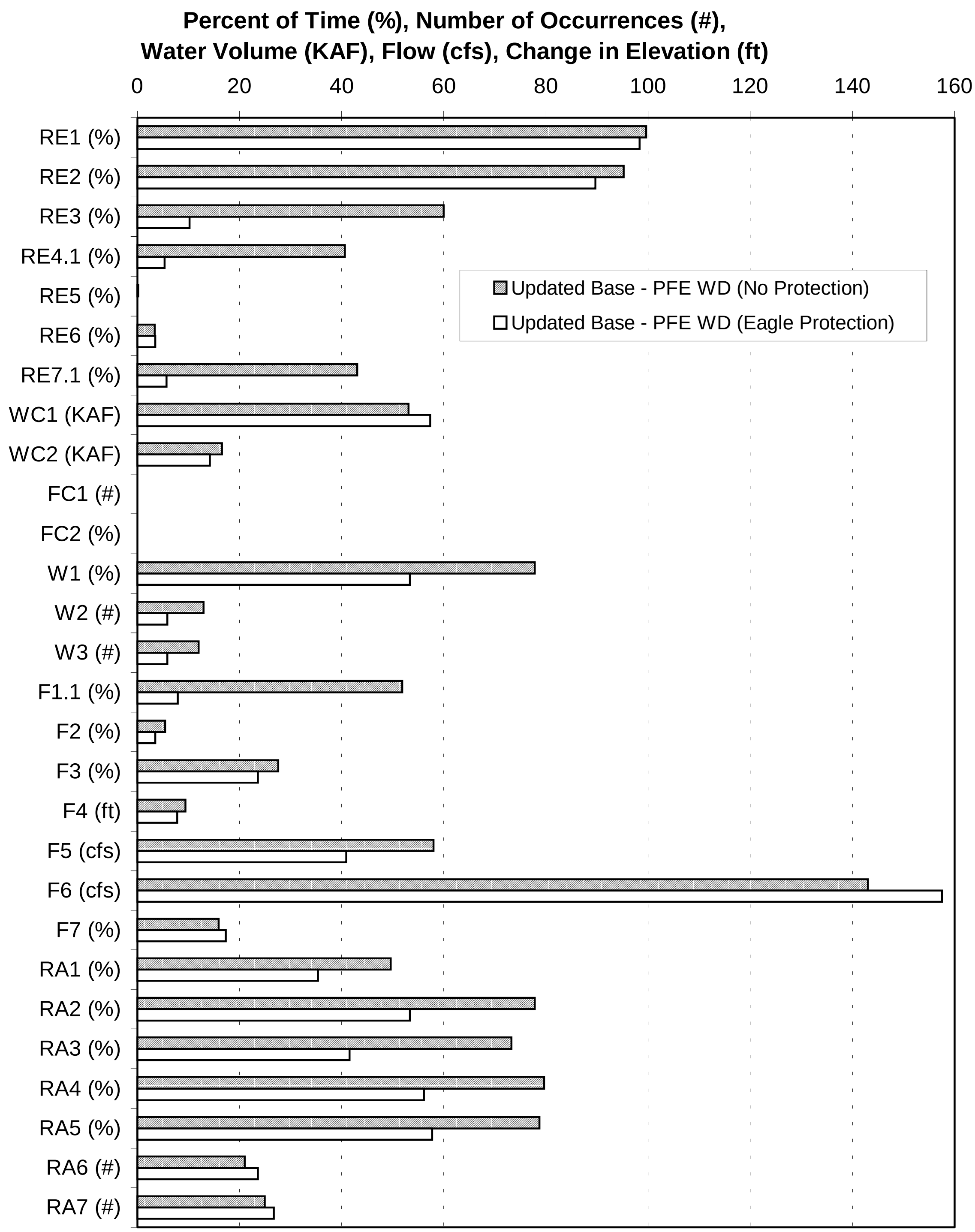

Figure 3.12 Performance Indicator Profiles: With and Without Eagle Nest Protection

to drop below 1,100 feet elevation much more often. Figure 3.12 shows that W1, the percent of time the WSE is greater than or equal to 1100 feet, decreases from 78% (with no nest protection) to 53% (with nest protection). Under the scenarios tested, the risk of flooding a nest in a year can be reduced from 18% to 5%, but at a cost of 25% more days that the forage area is below a level deemed adequate.

Operating to protect against eagle nest inundation would also impact other listed species dependant on the riparian corridor. Figure 3.12 shows large decreases in performance for several of the riparian evaluation criteria. Five of the performance indicators (RA1 - RA5) are 27% to 43% lower under the eagle nest protection policy.

These results illustrate one of the most challenging aspects about managing Alamo Reservoir. If the reservoir is managed to try to reduce harassment and nest inundation for the bald eagles, then other listed species are impacted in a negative way. In fact, even the bald eagles are impacted negatively due to more frequent low lake levels.

CONCLUSIONS

This chapter presents several technical methods to quantify trade-offs between different management alternatives under uncertainty based primarily on Monte Carlo simulation. The ongoing policy debate involving operation of Alamo Dam in Arizona is used to provide a real context. In the Alamo debate, like in most contexts, multiple sources of uncertainty exist. Different sources of uncertainty often need to be represented differently. This study emphasized methods that attempt to characterize a very complex problem in a relatively simple manner. The methods used to analyze, interpret and present the technical information produced using models rely heavily on indicators and indexes to distill the large amounts of information into useful forms. Several potential pitfalls of this method are described along with other methods to help balance these shortcomings. Finally, these technical methods are used to estimate trade-offs the resources managers face when balancing competing needs of multiple listed species.

In the case of the Alamo policy debate, the Corps plans to use the estimates of tradeoffs to work with the U.S. Fish and Wildlife and the Arizona Fish and Game Department to refine the operating strategy for Alamo Dam to balance the needs of the listed species over a long time horizon. This technical information is being used to help raise the level of understanding about the system and how changes in operation affect different interests over time.

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Chapter 4:

Optimization as an Independent Opinion in Central and Southern Florida

INTRODUCTION

This chapter describes application of an optimization model to central and southern Florida, a large-scale water management system. This study illustrates an indirect way that technical analysis can be used to support policymaking, as discussed in Chapter 2. In this instance, the US Army Corps of Engineers commissioned an optimization study (including model development) specifically designed to help analysts. The optimization model and study results were never intended for use by “decision-makers” directly. Rather, the study was intended to help existing modelers and technical analysts further their understanding of the system.

The review of this application contains an overview of the central and southern Florida system, a description of the model formulation, some interesting technical challenges faced in representing the system, and representative and interesting results from the model application.

STUDY OBJECTIVE

This study provided additional modeling support for the feasibility phase of the Central and Southern Florida Project Comprehensive Review Study (“Restudy”). The Jacksonville District of the US Army Corps of Engineers and the South Florida Water

Management District was performing the Restudy. The study included the following tasks:

- Development of a network flow programming optimization model to represent the South Florida water management system. This task included developing a reasonable network configuration, assembly of hydrologic data, and formulation of penalty functions to represent the operational goals and constraints of the system.
- Analysis of the existing system under base conditions and comparison with existing simulation models for model verification.
- Analysis of future conditions with and without various structural alternatives.
- Comparison and evaluation of alternatives based on environmental and water supply criteria.
- Preliminary assessment of operating rules and strategies for new facilities and the existing system.

As mentioned above, analysts from the Jacksonville District and the South Florida Water Management District wanted this model and analysis to help them in their efforts to provide relevant technical information and recommendations to their policy representatives. The analysts, whom had already developed models of the system and had been studying the problems and proposed solution, saw this study as an opportunity to improve and / or validate their recommendations to policymakers. This study was designed to:

- Provide independent model results for comparison to existing models

- Compare relative performance of optimization versus simulation models for this system
- Screen possible new alternatives
- Generate new ideas regarding operation rules and system changes
- Promote learning about water system interactions.

BACKGROUND

Central and Southern Florida System

The Central and Southern Florida (C&SF) Project was first authorized by Congress in 1948 to provide flood control, water supply for agricultural and urban uses, water supply for Everglades National Park, to prevent saltwater intrusion, and to protect fish and wildlife resources. Major areas of the project include the Kissimmee River, Lake Okeechobee, Everglades Agricultural Area, Water Conservation Areas, Lower East Coast, Native American tribal lands, Everglades National Park, Big Cypress National Preserve, and Florida Bay, as shown in Figure 4.1. The primary system includes about 1,000 miles of levees and canals, 150 water control structures, and 16 major pump stations and was completed in the mid-1960s.

Prior to development, the wetlands of southern Florida covered approximately 8.9 million acres. The region contained broad areas of sawgrass marsh, sloughs, wet prairies, cypress swamps, mangrove swamps, and coastal lagoons and bays. Each of these landscapes had natural hydrologic connections with the others. Water flowed southward from the headwaters of the Kissimmee River to Lake Okeechobee, where it periodically

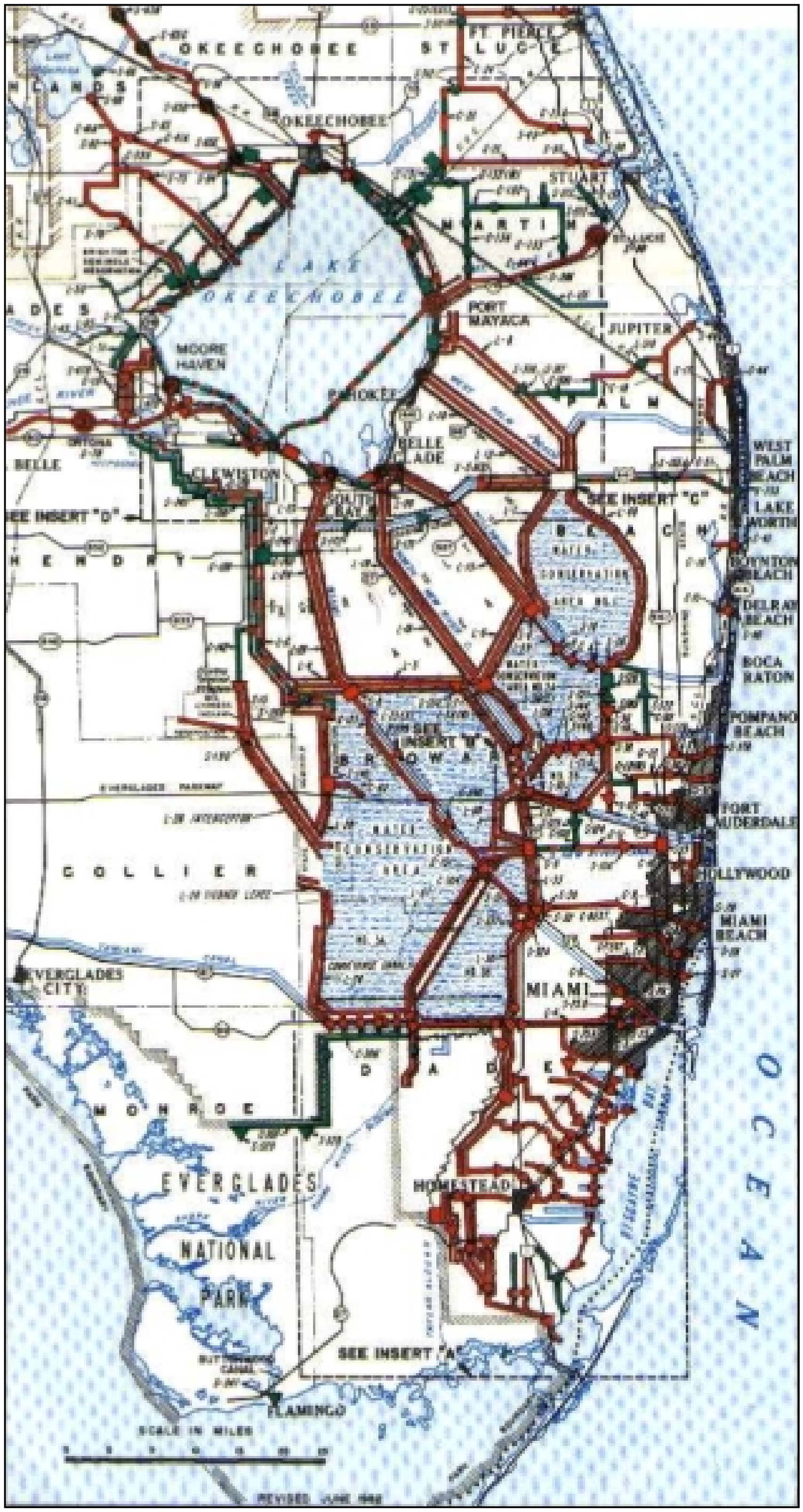

Figure 4.1 Central and Southern Florida Region

overflowed the lake’s southern banks to send sheets of flow through the expanse of sawgrass marsh to other natural communities.

Over the past century, growth-oriented land use and water management practices in central and southern Florida have degraded regional wetlands. Not only has the spatial extent of the wetland region been diminished, but dynamic hydrologic patterns also have been altered severely, as large amounts of water have been drained from the system into the ocean. In general, these actions have disrupted complex natural habitats and reduced the vigor and abundance of the natural system. The number of nesting wading birds has declined steadily with only a few exceptions since the 1960s, and the viable populations of other wide-ranging animals have been reduced (Storch 1973, Redfield 1999).

Meanwhile, the population and economy of central and southern Florida have continued to grow. The region is currently populated by more than six million people and contains seven of the ten fastest-growing metropolitan areas in the country. The region supports a large agricultural economy, but population growth is fueled primarily by a huge tourism industry. In-migration of retirees and immigration also has contributed substantially to the region’s growth (SFWMD 1985).

Despite the negative changes that have occurred, and the potential for increased stress on the environment in the near future, opportunities exist for recovering wetland systems in central and southern Florida. Scientific understanding of the ecosystems has steadily increased. Nearly all of the characteristic species still exist, though in smaller numbers. Large areas of wetlands remain, and much of the original area is publicly owned. Thus, there is reason to believe that many of the hydrological and ecological links of the original system can be restored.

Reevaluating Policy

The C&SF Comprehensive Review Study ("Restudy") was authorized by Section 309(1) of the Water Resources Development Act of 1992 (P.L. 102-580) to help restore some of the hydrological and ecological links of the original system. This document directed the Corps to restudy the project and determine whether modifications were necessary "due to significantly changed physical, biological, demographic, or economic conditions, with particular reference to modifying the project or its operation for improving the quality of the environment, improving protection of the aquifer, and improving the integrity, capability, and conservation of urban water supplies affected by the project or its operation." The Restudy was also authorized by two resolutions of the Committee on Public Works and Transportation, dated September 24, 1992. The first resolution directs the Corps to determine if the C&SF Project should be modified "in the interest of environmental quality, water supply, and other interests." The second resolution mentions specifically "other interests for Florida Bay including a comprehensive, coordinated ecosystem study with hydrodynamic modeling of Florida Bay and its connections to the Everglades, the Gulf of Mexico, and the Florida Keys Coral Reef ecosystem." (For more information about the Restudy and other work and issues in central and southern Florida refer to www.sfwmd.gov.)

Planning by the Corps of Engineers for water resources projects is accomplished in two phases–a reconnaissance phase and a feasibility phase. The objectives of the reconnaissance phase are to define the problems and opportunities in the study area, assess Corps and local roles in solving the problems, and develop and evaluate preliminary concepts to address the problems (USACE 1990). Completed in November

1994, the reconnaissance study identified various feasibility studies that could be implemented as separate elements, including the Comprehensive Review Study Including Water Preserve Areas (”Comprehensive Study”), the Indian River Lagoon Feasibility Study, and the L-28 Levee Modifications Feasibility Study.

The overall objective of the Comprehensive Study, performed by the Jacksonville District in partnership with the South Florida Water Management District (SFWMD), is to present a report to Congress that describes and justifies features of a recommended project. Accomplishing this objective requires identification of planning objectives, development of alternative plans to meet objectives, and evaluation of alternatives to arrive at a recommended plan.

MODEL FORMULATION

As mentioned above, analysts for the Jacksonville District and SFWMD had already been studying possible changes to the central and southern Florida system as part of the Restudy. The analysts had gathered extensive data and used a variety of models to help better understand system performance under existing and proposed conditions. Ultimately, the analysts wanted to select a few alternatives that they could recommend to policymakers as ways to improve system performance.

This process of evaluating and selecting the “best” alternative plans are typically performed using (1) enumeration-with-simulation or (2) mathematical programming (optimization). Enumeration-with-simulation techniques are used to find the most promising policies or plans by nominating trial plans and evaluating their efficiency in a simulation process. After a number of iterations, the “best” plan is considered the one with the best performance of all those evaluated (typically between one dozen and one hundred). The efficiency and success of this type of solution procedure depends on the ability to nominate “good” alternative plans for evaluation. Identifying promising plans can be difficult for a complex system.

Mathematical programming (also called optimization or prescriptive) techniques can complement enumeration-with-simulation techniques. An optimization model can be used to generate alternatives that best meet specific objectives subject to a set of constraints. The objectives are specified as a mathematical function that represents what the change is meant to accomplish, and the constraints represent limits in the system such as physical and legal requirements (Jensen 1987, Labadie 1997).

HEC-PRM

The optimization tool used in this study is the HEC Prescriptive Reservoir Model (HEC-PRM). HEC-PRM was originally developed for a study of the operation of the Missouri River main-stem reservoirs (USACE-HEC, 1991, 1992). It has also been extended and applied successfully to studies of the operation of the Columbia River system (USACE-HEC, 1991) and Alamo Reservoir in Arizona (USACE-HEC, 1998).

HEC-PRM represents a multi-period reservoir-system operating problem as a minimum-cost network flow problem. All water conveyance and storage facilities are represented as arcs in the network. Goals of and constraints on system operation are expressed through functions that impose penalties (costs) for various levels of storage or flow on the network arcs. The objective is to determine the spatial and temporal allocation of water that minimizes the total penalty for the entire network. Additional details of HEC-PRM can be found in the program user’s manual (USACE-HEC, 1994).

HEC-PRM provides a general framework for representing any reservoir system. To specifically evaluate a particular system, data must be prepared and formatted as inputs to the HEC-PRM software. The set of formatted data used to represent the C&SF system in HEC-PRM is referred to as the C&SF PRM model. Formulating the data to model the C&SF water management system comprised the following tasks: (1) specification of the network structure of the system, (2) assembly of hydrologic data, (3) development of techniques to model evaporation and seepage, and (4) formulation of penalty functions to represent water supply goals, environmental goals, and logical operational constraints.

Network Structure

Application of HEC-PRM requires the physical water management infrastructure to be represented as a closed network. The C&SF water management infrastructure contains a very complex system of storage areas, levees, canals, and release structures. The system was simplified as much as possible while maintaining the elements necessary for the intended study. Figure 4.2 is a schematic representation of the network in the C&SF PRM model.

Network models consist of a number of conveyance (flow) arcs and nodes. Flow arcs transfer water through space (from node to node) within a given time period. In the C&SF PRM model, each flow arc has a maximum flow capacity if relevant, and a minimum flow of 0 KAF/month.

Nodes in the model represent locations where flow arcs converge or diverge. There are four types of nodes in the C&SF PRM model: storage, demand, groundwater, and junction nodes. The six storage nodes in the model represent Lake Okeechobee and

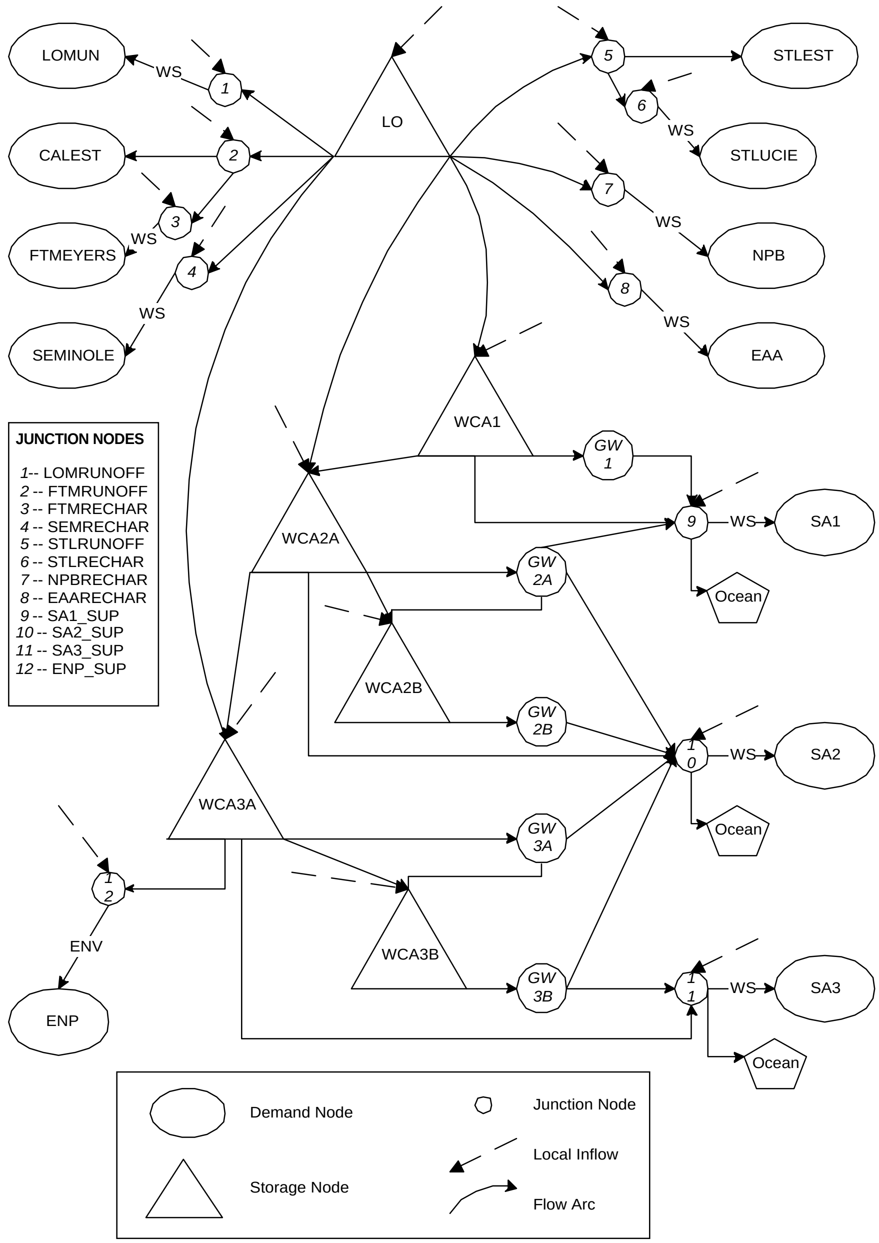

Figure 4.2 Network Schematic for Initial C&SF PRM Model

the five water conservation areas. Storage volumes in these areas are represented by flows in arcs that transfer water through time. Maximum and minimum storage levels are represented as flow constraints on these arcs, and evaporation is modeled by applying proportional loss factors (negative gains) to the flow arcs.

The twelve demand nodes in the model represent areas that use water from the storage areas. Flow into each demand node is subject to a water supply penalty function.

The five groundwater nodes in the model represent seepage from beneath the levees on the eastern side of the Water Conservation Areas. These nodes have no storage capacity, based on the assumption that all seepage flowing to these nodes in any given month is either extracted for consumption or flows to the ocean within the same month.

The twelve junction nodes in the model connect flow arcs to allow observation of intermediate flows of interest. These nodes are used to introduce local inflows, allow seepage from one storage node to be split to multiple destinations, and allow multiple inflows to converge before being subjected to a water supply penalty function.

Inflows

The network model also includes eighteen inflow arcs, modeled as external flows to the network. Flow time series on these arcs are inputs to the model. Typically, these flows would correspond to known inflows from the historical record or inflows generated from a statistical model. In the C&SF PRM model, inflows actually comprise a number of different quantities that affect the water balance at a point in the system. These quantities include historical local inflows, changes in storage (i.e., “delta storage” values derived from the South Florida Regional Routing Model data), evaporation adjustments, and variations in water demand. The period of record used for this model extends from January 1965 through December 1989.

Penalty Functions

One of the most important elements of a prescriptive (or optimization) model such as HEC-PRM is specification of an objective function. In HEC-PRM, the objective function is specified using penalty functions. These functions define, as a function of flow or storage, the economic, social, and/or environmental costs of deviating from ideal operation for each of the system operating goals (e.g., water supply, environmental needs, flood control, recreation, navigation, and hydroelectric power). The penalty functions serve to define the desired flows and storage levels for each location in each season, as well as establish the relative importance of various goals when trade offs are necessary.

Due to a lack of economic data, penalty functions for the C&SF PRM model were computed using the Relative Unit Cost method developed in earlier HEC-PRM studies (USACE, 1998). According to this method, penalty functions are determined by specifying important "break-points" in system operation, including critical storage and flow levels for various objectives. Then, between these break points, unit costs are assigned to represent the relative importance between meeting various objectives. The C&SF PRM model also includes atypical penalty functions designed to model seepage from the water conservation areas. These special purpose penalty functions are discussed below.

Water Supply

Nine arcs have monthly varying water supply penalty functions. The water demand levels for the C&SF PRM model were set based on the maximum monthly demand for each demand node experienced over the study record (January 1965 - December 1989). This maximum monthly value is considered the point of zero penalty for each demand node. For values ±10% of the maximum monthly demand, a unit cost of 0.01 (or -0.01) is assessed. During the wet season, a unit cost of ± 0.05 is assessed for values between ±10% and ±20% of the maximum monthly demands. During the dry season, this same unit cost is assessed for values between ±10% and ±30%. For values beyond ±20% (or ±30%), the unit cost is ±1. See Figure 4.3 for a graphic example.

Local demands are highly dependent on the local rainfall. To reflect this variability, time series of "demand adjustments", represented as inflows to reduce demands from maximum levels, have been added at the junction nodes just upstream of the water supply penalty. The demand adjustments are computed by subtracting the historic time series of demands from the maximum monthly demands. Each adjustment time series represents the impact of local rainfall and climate on local demand.

Storage

Storage penalties for this model formulation only occur on Lake Okeechobee and Water Conservation Areas 1, 2A, and 3A. The penalties are only for low storages. Penalties for high storages, designed to value flood control space, were not added to the initial (validation) formulation to see how the operation compared to existing operation. Storage penalties based on maintaining flood control space were added for later model formulations used to evaluate possible additions to the system.

Environmental

The demand for water in the Everglades National Park is modeled using a penalty function similar to the urban water supply penalty functions described earlier. However,

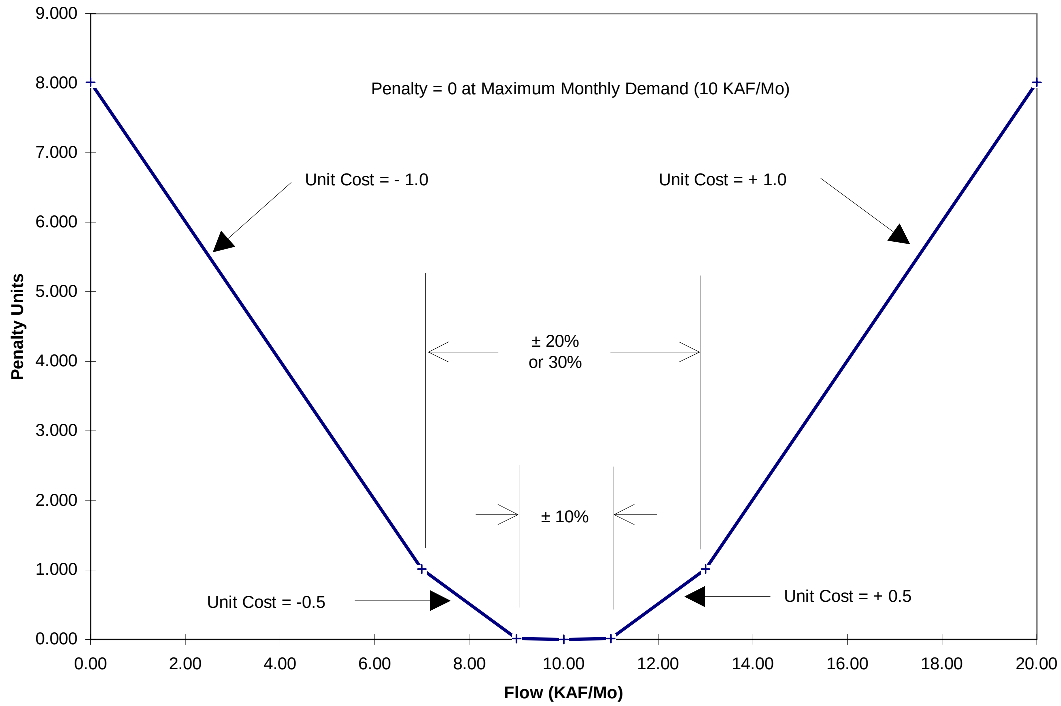

Figure 4.3 Example Water Supply Penalty Function

for the preliminary testing, no penalty was applied for water deliveries greater than the desired flow. No penalty functions were applied for flows to the St. Lucie or Caloosahatchee estuaries for the preliminary formulation. These penalty functions are included in later formulations.

Persuasion

All of the arcs representing surface releases from the water conservation areas have a constant unit cost of 0.001 assigned to them. This small penalty specifies that storage is preferred over releases when all other things are equal.

MODELING CHALLENGES

In some ways, the central and southern Florida system can be modeled like any other reservoir system. Representing storage reservoirs and conveyance using a closed network is the same as a reservoir system anywhere. However, the topography and hydrogeology in central and southern Florida are quite different from most other reservoir systems in the United States. The storage areas in the C&SF region are large and shallow. This characteristic means the elevation-area-capacity relationship is substantially different than a reservoir built in a river canyon. This peculiarity presented some challenges when representing evaporation in HEC-PRM.

Another difference is the high degree of interaction between the storage areas and the groundwater aquifers. The aquifers are limestone with high hydraulic conductivity. In fact, surface releases from the storage areas are rare. Typically, water supplies are extracted from groundwater wells that are fed through seepage from the storage areas. As a result, the operation of the system depends largely on the rapid underground travel of water from surface storage to demand points. The amount of water that seeps from a storage area depends on changes in head in the reservoir and as a result need to be modeled using non-linear equations. Representing this non-linear process can be difficult with a linear programming model, and particularly with a more restrictive network flow programming model.

Another technical challenge was encountered while trying to represent seepage from the storage areas. Geographically, water that migrates from a storage area through the groundwater aquifers can be withdrawn in different demand areas. This phenomenon requires that water seeping from one storage area be split (or divided) according to some observed behavior as it flows to demand areas.

Evaporation

In HEC-PRM evaporation from a reservoir is calculated as a simple linear function of storage, given an evaporation rate (ft/mon) and an area-storage factor (K acres/K acre-ft) for the reservoir. Normally, the area-storage factor can be approximated using the slope of the best-fit line through the area-storage curve. However, the area-storage relationships of the lakes and water conservation areas in central and southern Florida cannot be represented adequately this way because of their shape: large and shallow. To overcome this difficulty, the area-storage curves were regressed over selected ranges without the condition that the intercept be zero. The selected ranges were chosen based on the storage levels most likely to occur in the HEC-PRM model run. These ranges were selected initially based on results from the Natural System Model (NSM) and adjusted after studying results from several C&SF PRM formulations. Then, to meet the form required by the HEC-PRM model input, the regressed lines for the select storage ranges were adjusted such that the line passed through the origin (i.e., the slopes remained the same, but the intercepts were set to zero).

By adjusting each regressed line such that it passes through the origin, evaporation will be underestimated over the range where the regression was performed. To account for this, a time series of evaporation “corrections” was calculated and subtracted from the local inflows to the corresponding storage area. The evaporation corrections were computed by multiplying the regressed intercept, which represents the vertical difference (or surface area in K acres) between the original and adjusted regressed lines, by the time series of evaporation rates (ft/mon) for each storage node.

Figure 4.4 show area versus storage curves for Lake Okeechobee along with the original and adjusted regressed lines used to represent the Lake Okeechobee area-storage relationship in C&SF PRM. The slopes (m) and intercepts (b) are indicated on the plot, along with the range of values used in the regression. This was done for each storage area.

Seepage

Previous applications of HEC-PRM have not considered seepage based on dynamic storage levels. For many reservoir systems, the seepage values are small in comparison to other flows and therefore need not be considered explicitly. However, for the C&SF water management system, seepage is a major means of water conveyance from the Water Conservation Areas. Since the water conservation areas in the south are formed by levees built over porous limestone formations, and the ground water aquifer has a high rate of conductivity, the seepage rates beneath the levees are quite high. The groundwater gradient causes water to flow through the aquifer from the Water Conservation Areas eastward towards the Atlantic Coast, where urban areas utilize some portion of this water with a network of groundwater wells.

Representing the seepage in HEC-PRM was one of the more challenging aspects of this study. A general network flow model does not have the capability of considering information, or relationships, between multiple links. One characteristic of network flow models that contributes to their efficiency is the simplified form of the objective function and constraints. They are restricted to unit costs and bounds for a single arc. No

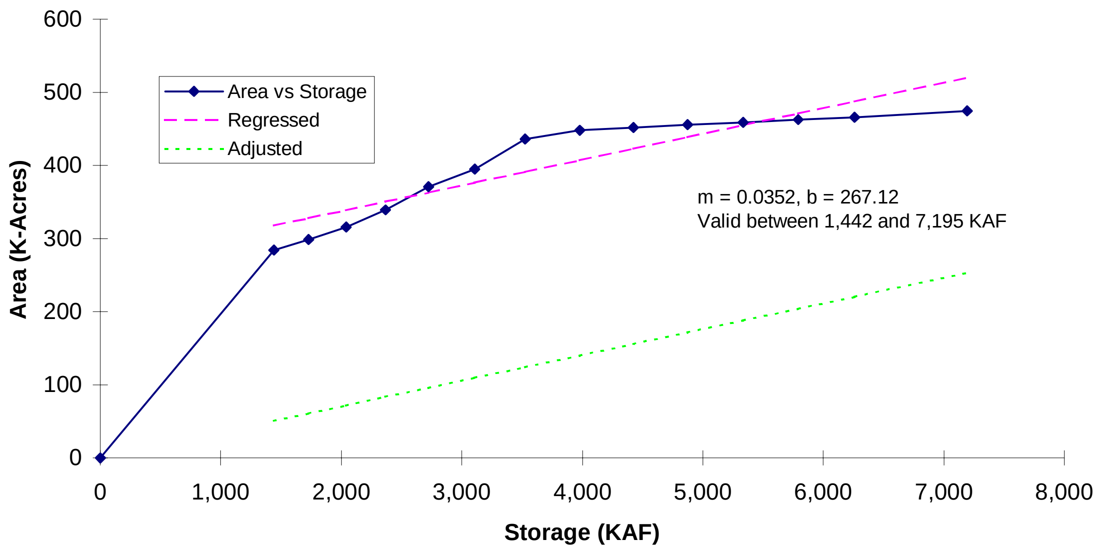

Figure 4.4 Lake Okeechobee Area-Storage Relationship with Regressed Approximation

penalties can be constructed to relate flow across one arc to flow across another. This type of formulation is possible with a general linear programming solver, but with significant tradeoffs in computational efficiency.

The algebraic representation of a generalized network flow with gains problem is:

$$Min. \sum_{k=1}^{m} h_k f_k$$

$$s.t. \quad \sum_{k \in M_{Oi}} f_k - \sum_{k \in M_{Ti}} a_k f_k = b_i \quad i = 1, \ldots, n-1$$

$$f_k \le c_k \quad k = 1, \ldots, m$$

$$f_k \ge 0 \quad k = 1, \ldots, m$$

Where h_k is the unit cost of flow through arc k,

f_k is the flow through arc k,

a_k is the gain factor on arc k, and

c_k is the upper bound for arc k

This simplified (and restricted) form of linear programming allows for rapid solutions but does not allow constraints to be written involving multiple links.

One of the technical challenges during the formulation of the C&SF PRM model was how to relate seepage to storage levels using a network flow programming formulation. This problem is similar to the problem of representing hydropower generation that is dependent on both flow and storage, or hydrostatic head. HEC-PRM includes a routine that can be used to approximate hydropower operations through an approach called successive linear approximations. The solution technique involves an iterative approach that makes adjustments to the network flow parameters and re-solves in a systematic way (Martin 1995). Though similar, the seepage problem has one significant difference that prevents use of the hydropower algorithm in its standard form. Specifically, in hydropower operations there is some value to maintaining storage for future periods, and this is considered for current period releases in the HEC-PRM hydropower routine. For seepage, however, current seepage rates should be determined strictly by the current storage levels. Therefore, the hydropower algorithm was modified to represent seepage for the C&SF PRM model. The HEC-PRM hydropower algorithm requires input data that characterizes the value of power produced for reservoir storage levels and releases. This information is characterized as a family of curves.

Since seepage cannot be valued in the same manner as hydropower, a special set of penalty functions were designed to match the required input format and achieve the desired interaction between surface storage conditions and seepage flows under the storage area levees. The penalty functions were designed to cause HEC-PRM to produce seepage amounts related to storage levels as approximated in the South Florida Regional Routing Model (SFRRM):

SEEP = HP * LEN * COEFF

where HP is the head potential (ft),

LEN is the length of the levee (miles), and

COEFF is the seepage coefficient (cfs/ft/mile).

To calculate the seepage values used to formulate the penalty functions, the head potential was determined by assuming a tail water elevation and subtracting that from the current period elevation in the storage area causing the seepage. These parameters were used to calculate seepage values at various water elevations in the Water Conservation Areas. Elevations were chosen to produce penalty curves spaced evenly across the range of possible storages. The HEC-PRM hydropower algorithm works with paired data functions of penalty curves for different storages. The penalty functions were formed by setting the penalty equal to zero at the seepage level calculated for the corresponding storage level and then a unit cost of ± 500 was used to compute the penalty for seepages other than the calculated value. Unit costs of ± 500 are much higher than the other unit costs, so one of the seepage values at zero penalty should always be selected. Since the hydropower algorithm does not interpolate between the storage curves, the curve closest to the current period storage is selected. Thus, if finer resolution is desired for the seepage results, more penalty curves can be specified.

Seepage penalties for the hydropower algorithm are in place for the links between WCA1 to GW1, WCA2A to GW2A, WCA2B to GW2B, WCA3A to GW3A, and WCA3B to GW3B. Figure 4.5 is a plot of the seepage penalty functions for WCA1. The

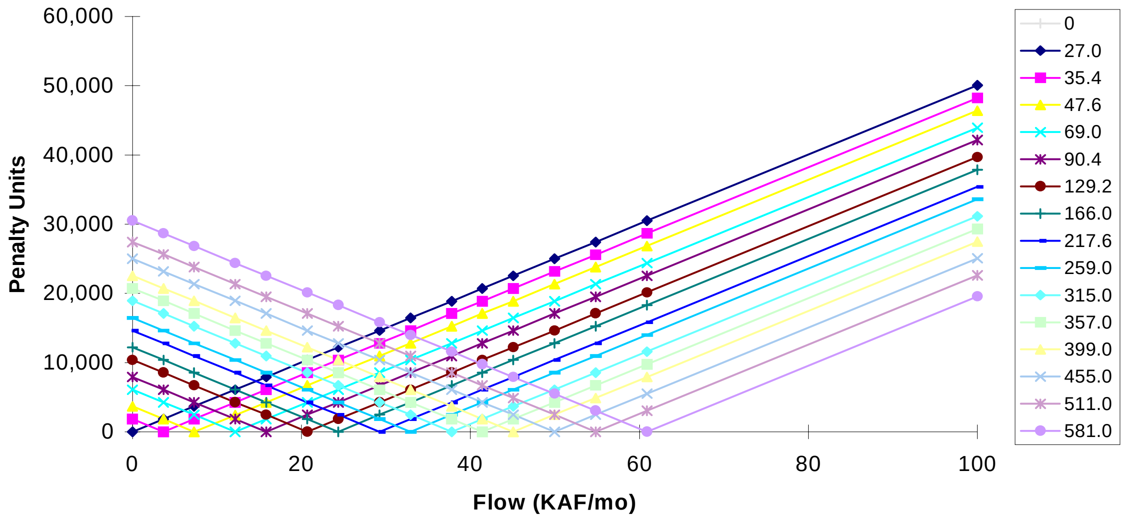

Figure 4.5 Seepage Penalty Functions for Water Conservation Area 1

different curves represent penalties for different storage values. Figure 4.6 is a comparison of the resulting C&SF PRM seepage values for WCA1 and the estimated seepage values that should occur from WCA1 given the monthly pattern of stages.

Flow Split

Once the appropriate quantity of water has been directed to the groundwater nodes as seepage, the flow is divided and delivered to different nodes to reflect the physical system of seepage from one storage area being utilized in different demand areas. This is accomplished in C&SF PRM using a penalty scheme to "split" the seepage flows to different destinations according to the ratio computed with the seepage equation used in the SFRRM. For example, seepage from WCA2A flows to the GW2A node and is split between SA1_SUP, SA2_SUP, and WCA2B according to the specified ratio. These ratios are not constant over the range of possible storage levels in the conservation areas due to different tail water elevations at the destination nodes (see Table 4.1).

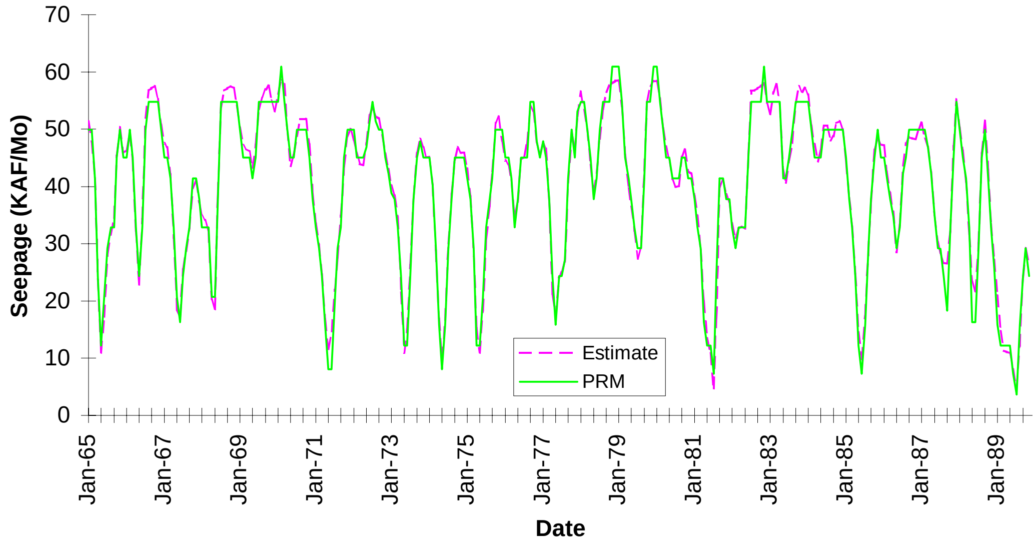

Figure 4.6 Seepage Time Series from WCA1: C&SF PRM vs. Calculated Estimate

Table 4.1: Seepage Parameters for C&SF PRM Model

Location	Length	Coefficient	Tail Water Depth
GW1 to SA1_SUP	29.2	6.9	14.0
GW2A to SA1_SUP	4.0	3.96	14.0
GW2A to WCA2B	10.0	3.96	8.0[1]
GW2A to SA2_SUP	4.0	3.96	6.5
GW2B to SA2_SUP	13.8	9.9	6.5
GW3A to SA2_SUP	5.9	11.0	6.5
GW3A to WCA3B	24.5	11.0	7.0[2]
GW3B to SA2_SUP	7.9	11.0	6.5
GW3B to SA3_SUP	25.0	11.0	5.5

Notes: 1) Tail water depths for WCA2B and 3B are based on median values of NSM results.

Table 4.2 shows the relationship information used to compute flow split penalties for seepage out of WCA2A. The range of possible seepage amounts from WCA2A (0 to 47.41 KAF/mo) was divided into a number of segments. For the model, these segments

Table 4.2 Seepage Flow Split for WCA2A

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Segment	WCA2A Elevation (ft)	WCA2A Storage (KAF)	Seepage to GW2A (KAF/mo)	Seepage From GW2A to: SA1_SUP (KAF/mo)	SA2_SUP (KAF/mo)	WCA2B (KAF/mo)	Unit Cost
	6.50	3.5	0.00	0.00	0.00	0.00	
1	7.00	4.0	0.48	0.001	0.48	0.001	2
2	7.75	4.7	1.20	0.002	1.20	0.002	4
3	8.50	6.6	3.12	0.003	1.92	1.20	6
4	9.50	12.0	6.47	0.004	2.87	3.59	8
5	10.50	28.0	9.82	0.005	3.83	5.99	10
6	11.50	65.9	13.17	0.006	4.79	8.38	12
7	12.50	148.0	16.53	0.007	5.75	10.77	14
8	13.50	256.0	19.88	0.008	6.70	13.17	16
9	14.50	364.0	23.70	0.48	7.66	15.56	18
10	15.50	472.0	28.01	1.44	8.62	17.96	20
11	16.50	580.0	32.32	2.39	9.58	20.35	22
12	17.50	688.0	36.63	3.35	10.53	22.74	24
13	18.75	823.0	42.02	4.55	11.73	25.74	26
14	20.00	958.0	47.41	5.75	12.93	28.73	28

translate to a series of flow arcs with different unit costs used to convey seepage from one groundwater node to multiple destination nodes in a desired ratio. The columns in Table 4.2 represent the following:

(1) the segment number (where the arc connecting GW2A to SA2_SUP for segment 1 can convey between 0 to 0.48 KAF/mo),

(2) the water surface elevation that must exist to cause a total seepage amount shown in column 4,

(3) the water conservation area storage at the elevation shown in column 2,

(4) the total amount of seepage from the conservation area for the storage shown in column 3,

(5), (6), and (7) the amount of seepage that should arrive at SA1_SUP, SA2_SUP, and WCA2B respectively when total seepage arriving at GW2A equals the amount in column 4, and

(8) the unit cost applied to the arcs associated with the segment.

The seepage values shown in Columns 5, 6, and 7 were used as the independent variable for the penalty function values. Since the unit costs are set to be the same for each segment for each destination node, the network flow model will split the flow to the destination nodes as desired. Since the unit costs increase for every segment, the arcs will fill in the proper order. This approach guarantees that the desired flow split will be exact for flows entering the groundwater node that are equal to the values shown in Column 4. If the total seepage amount entering GW2A is between two of the values designated in Column 4, then the flow split will be correct up to the amount for the previous segment, but the remainder would not be split in the correct proportion. For example, if the seepage amount from WCA2A for a particular month were 11.0 KAF/month then HEC-PRM would correctly allocate 0.005 KAF/month to SA1_SUP, 3.83 KAF/month to SA2_SUP, and 5.99 KAF/month to WCA2B for a total of 9.82 KAF/month (Segment 5 in Table 4.2). However, the remaining 1.18 KAF would not be allocated in the desired ratio, since the model could put all of this flow in one or two of the arcs associated with Segment 6 (in fact, the model would be indifferent between the three arcs associated with Segment 6).

Due to the way seepage is represented in C&SF PRM using the hydropower algorithm and penalties as discussed earlier, the total seepage into GW2A will always match one of the values in Column 4 exactly, and therefore the desired ratio is always maintained in this model.

MODEL TESTING

Results from initial formulation of the C&SF PRM model were compared to results from two simulation models that have been used by the Jacksonville District and SFWMD for years to study and help operate the C&SF water management system. These results were compared at key locations in the system for storage and flow to verify that the C&SF PRM model reasonably represents behavior of the system. Upon comparison, the C&SF PRM model was determined to adequately represent system behavior. The C&SF PRM model provided similar stage results for the major storage areas with some exceptions. See Figures 4.7 and 4.8 for representative comparisons of monthly stages predicted by different models. Where the C&SF PRM model departed from other model behavior, the differences could be explained based on the different approaches: optimization versus simulation. After comparing C&SF PRM model results with existing simulation models the Jacksonville District and SFWMD analysts determined that the C&SF PRM model represented the existing system operations adequately. This base C&SF PRM model was then modified to evaluate different system alternatives.

APPLICATION AND RESULTS

The C&SF PRM model was modified to evaluate various structural alternatives for enhancing the C&SF system with respect to environmental and water supply criteria. Using estimated water demand levels for 2010, system performance with new projects was compared to performance under baseline conditions (no new projects). Additional

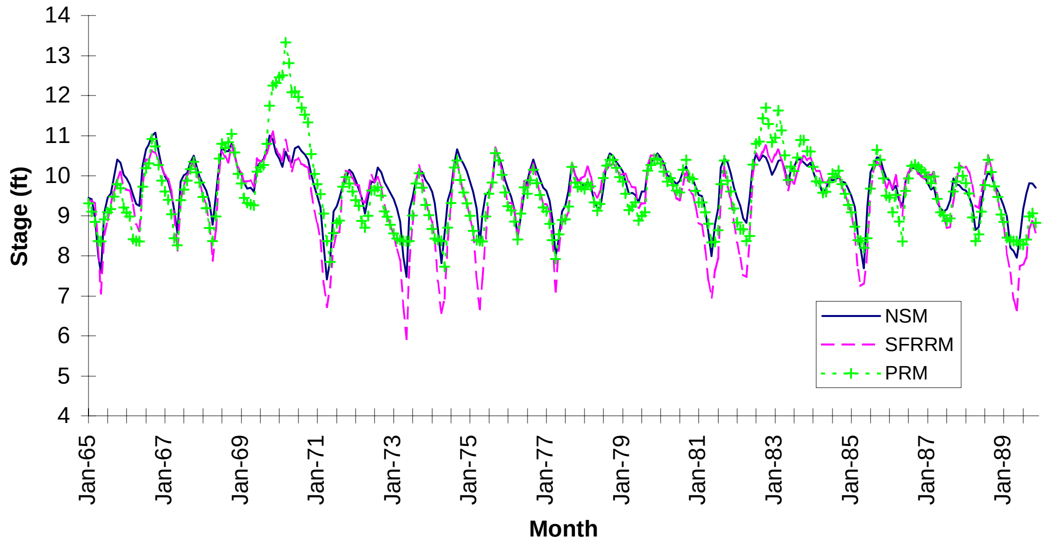

Figure 4.7 Lake Okeechobee Stage Time Series Comparison

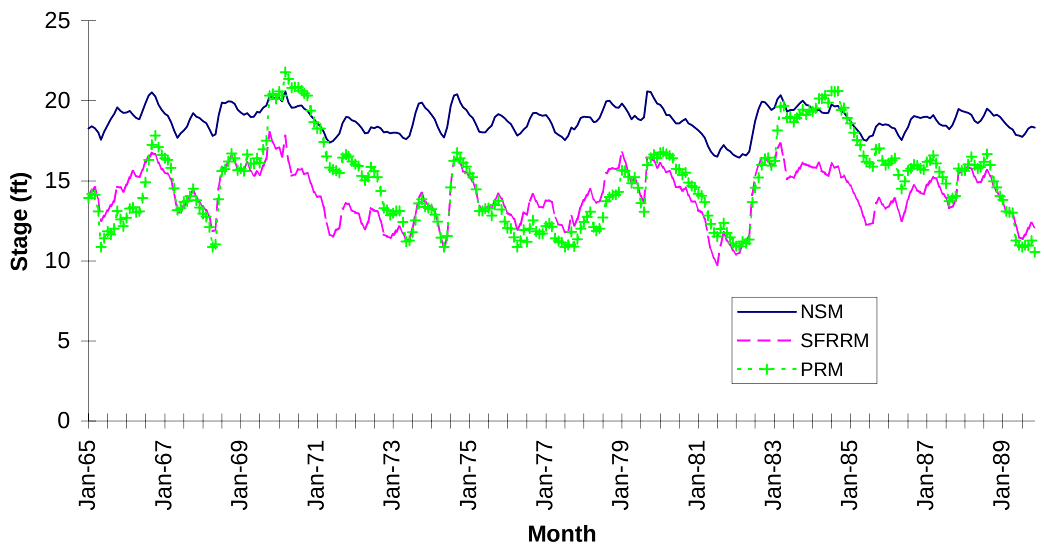

Figure 4.8 WCA3A Stage Time Series Comparison

analyses were performed to evaluate the proposed capacity of each project and gain insights into system operating strategies.

Description of Alternatives

Four new storage areas were evaluated as potential means of improving the performance of the C&SF water management system. These alternatives are summarized in Table 4.3. The North Storage Area is proposed as an 80 KAF water conservation area for flood control use when Lake Okeechobee water levels are high and for augmenting water supplies when the lake levels are low. The 160 KAF Caloosahatchee Storage Area is proposed to regulate flow to the Ft. Meyers demand area, with perhaps some secondary benefits for the Caloosahatchee Estuary. Similarly, the 40 KAF St. Lucie Storage Area is proposed to regulate flows to the St. Lucie Estuary, with secondary benefits for St. Lucie water supply. The EAA Storage Area is proposed as a 300 KAF water conservation area that can be used to regulate flows to the EAA demand areas as well as to WCA3A. Also proposed are structural modifications to increase channel capacities leading to and from the EAA Storage Area to 168 KAF/month (i.e., three times the existing channel capacity between Lake Okeechobee and WCA3A.

Model results for the addition of these facilities are presented, following

Table 4.3 Structural alternatives considered.

Alternative	Capacity (KAF)	Area (K Acres)	Pump In/Out (KAF/week)	Inflows	Comment
North Storage (NSTO)	80	10	70/25	None	Connected to Lake Okeechobee
EAA Storage (EAASTO)	300	50	N/A	Miami and NNR Canal inflow	Receives releases from LO; releases to WCA3A and EAA demand
Caloosahatchee Storage (CALSTO)	160	20	20/20	None	Releases to Ft. Meyers demand
St. Lucie Storage (STLSTO)	40	20	20/20	None	Releases to St. Lucie demand or estuary

presentation of some technical modifications needed for this 2010 C&SF PRM model.

Applying C&SF PRM Model

The network configuration was modified to accommodate the potential new storage areas and diversion links, as shown in Figure 4.9. Four storage nodes, two junction nodes, seven diversion links, and one inflow link were added to the network.

Water Supply Demands

Demand estimates provided by the Jacksonville District for the year 2010 were used to evaluate the structural alternatives. These estimates were incorporated in C&SF PRM by increasing the maximum monthly demands and the demand adjustments at four demand nodes. The factors used are given in Table 4.4. Increasing the maximum monthly demands and the demand adjustments by the same factor implicitly assumes that climate-induced variations in water demand will increase with the level of demand. This assumption may be invalid if demand reductions are due primarily to local water availability that is limited, or if the increased demand comprises uses which are insensitive to climate.

Everglades National Park Demands

Since restoration of the Everglades is a major goal of the Restudy, the water supply penalty function for Everglades National Park (ENP) was adjusted to account for higher target flows than considered in the model testing study. As before, a time series of target flows was used in the model by selecting the maximum monthly target flows to be the values at which zero penalty is incurred, while adding a time series of “demand adjustments” equal to the maximum monthly flows less the actual target flows. The time

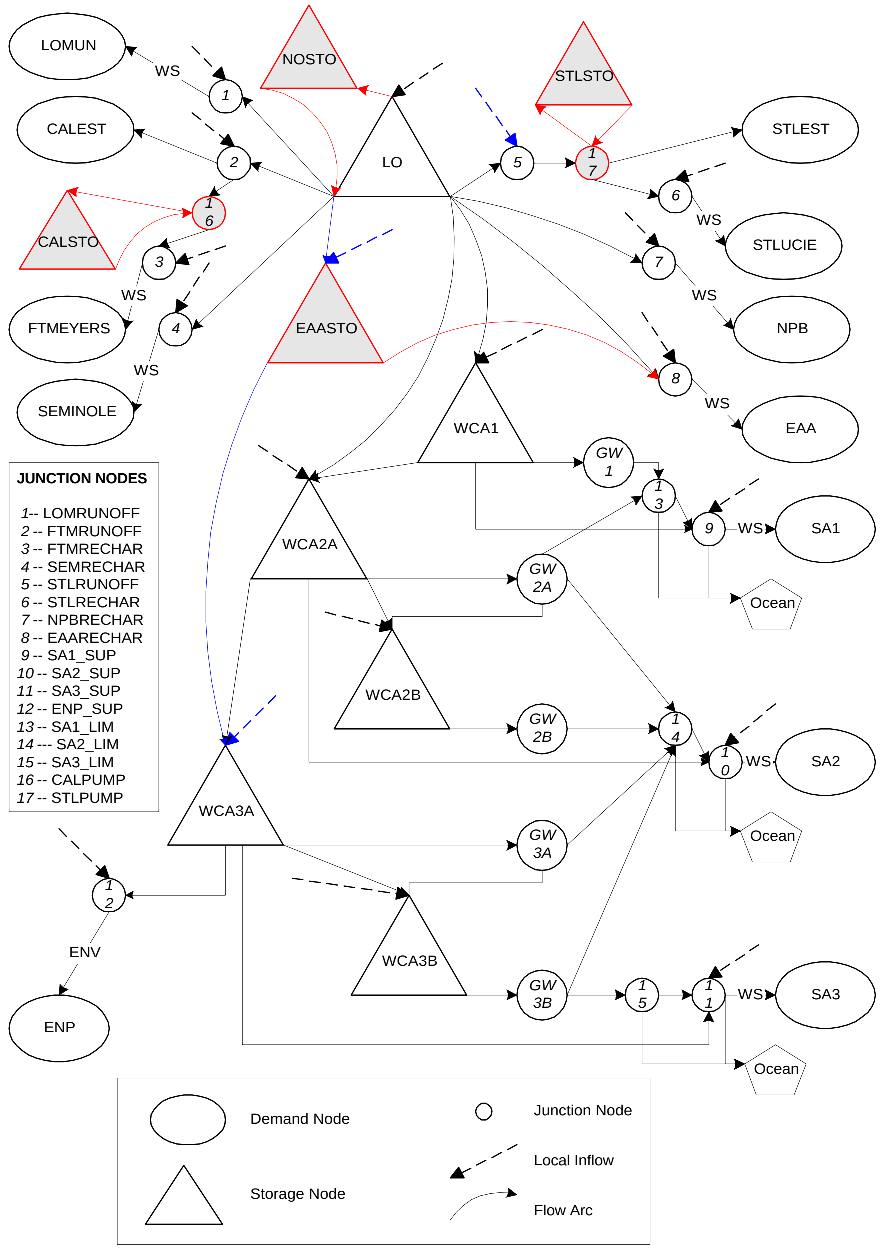

Figure 4.9 Revised C&SF PRM Network Configuration (Shading indicates new storage areas and nodes)

series of actual target flows is shown in Figure 4.10. The shape of the ENP water supply penalty function was also modified so that flows above the target levels (surpluses) are penalized less than flows below the target levels (shortages).

Table 4.4 Estimated water demand increases for year 2010.

Water Demand Node	Demand Factor
Ft. Meyers (FTMEYERS)	1.40
Service Area 1 (SA1)	1.48
Service Area 2 (SA2)	1.81
Service Area 3 (SA3)	1.49

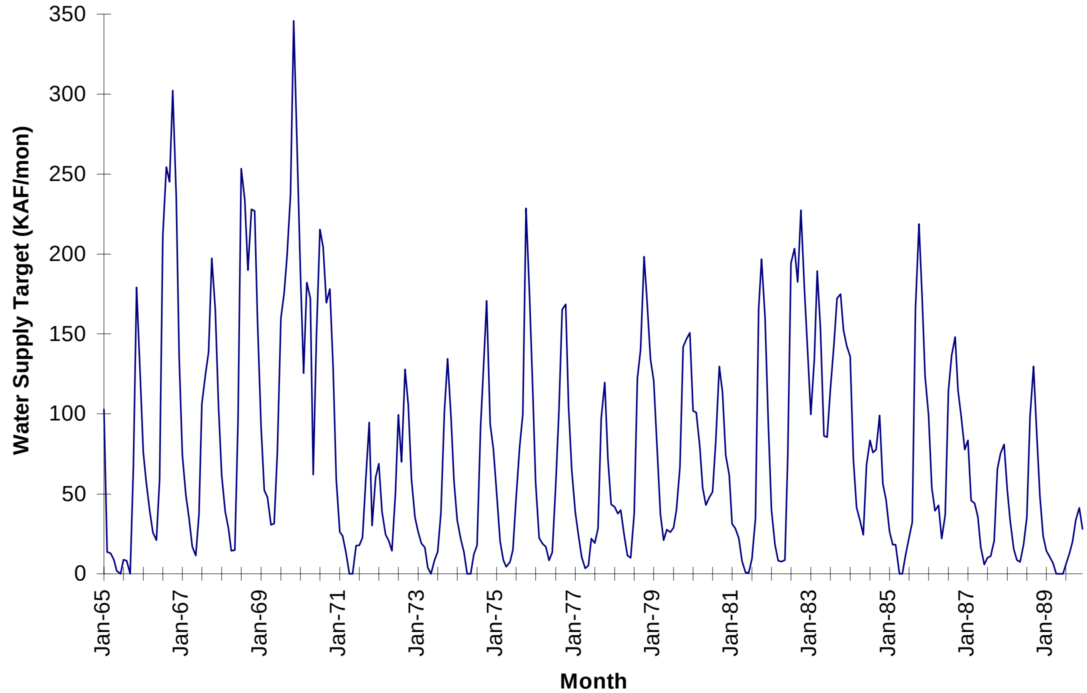

Figure 4.10 Everglades National Park water supply target

Evaporation from Proposed Facilities

Finally, evaluation of new storage areas requires a reasonable representation of evaporation from them. However, in lieu of detailed storage-area relationships, it was assumed that the new areas would have essentially flat bottoms with levees for “banks.” This assumption leads to the storage-area relationship shown in Figure 4.11, which

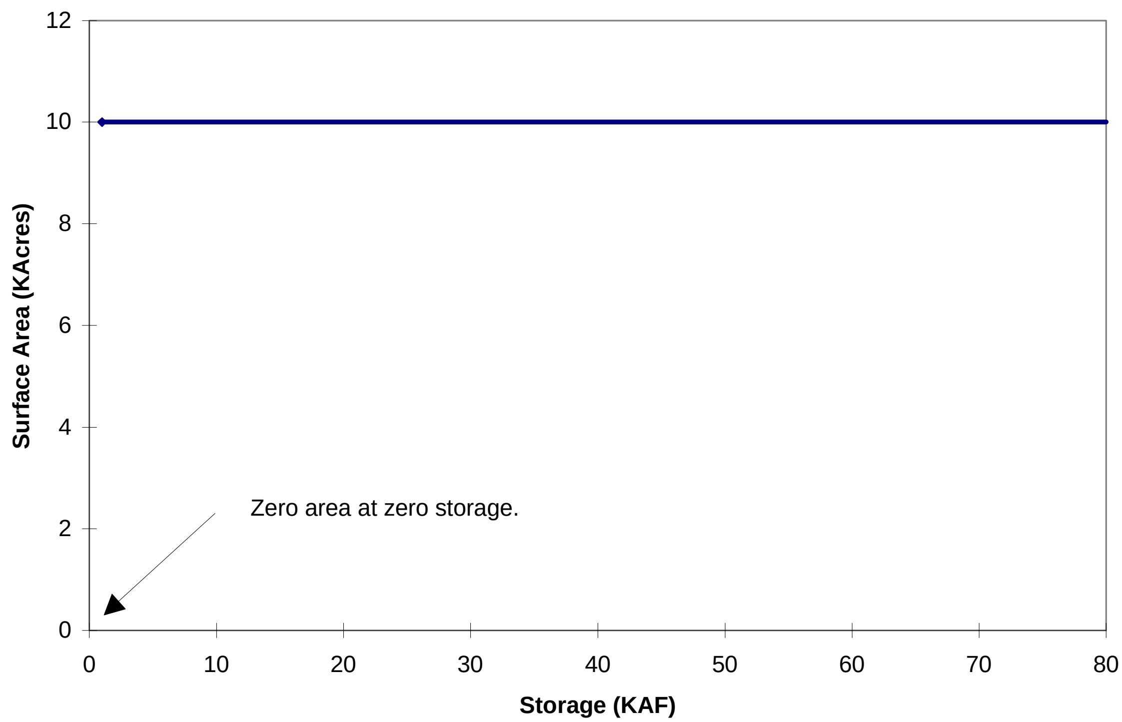

Figure 4.11 Assumed storage-area relationship for new storage areas

cannot be represented adequately in HEC-PRM. One approach to this problem is to estimate the storage-area relationship with a line through the origin (as allowed in HEC-PRM). This works well whenever the storage area is nearly full or empty, but leads to underestimation of evaporation at intermediate storage levels. A second approach is to model evaporation with a time series of evaporation losses at the storage node, as done in the validation phase of this study. This approach works well except when the storage area is empty or nearly empty–evaporation may be overestimated as the model is forced to divert water to the storage area to fulfill the mass balance constraint. After preliminary results showed that the North Storage Area tends to be either full or empty, while the other storage areas frequently operate at intermediate levels, the two evaporation schemes were applied appropriately to each area.

Model Results

Alternatives Studied

This section presents results from four different alternatives studied with C&SF PRM. The first alternative (“BASE 2010") represents baseline conditions at the year 2010. In this baseline alternative, the existing physical system is modeled using 2010 water demands, the penalty function modifications discussed above, and observed hydrologic data from a 25-year period (1965-1989).

The second alternative (“GRAND”) uses the same hydrologic data and penalty functions as BASE 2010 but considers the modified network, including all four new storage areas (Table 4.3) and the increased channel capacities. Results from GRAND were compared to those from BASE 2010 to evaluate the potential benefits of the structural alternatives.

The third and fourth alternatives (“GRANDU” and “GRANDU2”) are similar to GRAND except that structural capacity constraints are relaxed to estimate the potential benefits of larger projects. This is an attractive capability of an optimization model that cannot be done directly with a simulation model. In GRANDU, only the new storage areas are assumed to have unlimited capacity. In GRANDU2, both the new storage areas and the modified channels are assumed to have unlimited capacity. Results from GRANDU2, GRANDU, and GRAND were compared. In each of these runs, evaporation from the new storage areas was modeled using a combination of the two approaches discussed, essentially assuming that any storage capacity beyond the proposed capacity would be built to allow filling and withdrawal to occur in sections (to reduce surface area for lower storage amounts).

Summary Results

Results from the four alternatives are summarized in Tables 4.5 and 4.6. Deliveries to water demand nodes are summarized in Tables 4.5 and 4.6. Table 4.5 contains average annual flow values. Although there is a great deal of variability in demand and supply from year to year, these results show the average effect of the new storage areas and increased channel capacities. Comparison of results from BASE 2010 and GRAND suggests the structural enhancements allow the system to provide significantly more water to the EAA, North Palm Beach (NPB), and Ft. Meyers (FTMEYERS) demand areas, while more modest increases are seen at each of the other demand areas. In the case of the estuaries, the new storage areas provide increased flood protection, which results in an overall decrease in average annual flow. Analysis of results from the GRAND, GRANDU, and GRANDU2 strongly suggest that unlimited

Table 4.5 Average annual flows to demand nodes (KAF)

Demand Node	Base 2010	Grand	GrandU	GrandU2
CALEST	938.4	779.9	521.4	530.5
EAA	1744.5	1884.3	1885.0	1885.4
ENP	2434.8	2450.7	2438.8	2439.1
FTMEYERS	277.8	322.7	329.7	329.7
LOMUN	13.0	15.8	16.0	16.0
NPB	157.5	172.3	175.0	175.1
SA1	176.4	178.3	179.3	179.5
SA2	222.2	225.6	227.3	227.3
SA3	780.2	797.7	798.5	800.2
SEMINOLE	29.6	36.2	36.9	36.8
STLEST	222.2	165.8	68.4	68.5
STLUCIE	120.2	124.8	125.7	125.7

storage and conveyance capacities provide only minor benefits in terms of average annual values. Table 4.6 contains average annual shortages and surpluses at the demand nodes (surpluses only occur at EAA, NPB, and ENP). Results from GRAND show large reductions in average annual shortages at EAA, FTMEYERS, and STLUCIE. Smaller, but still significant, reductions are observed at the other demand nodes. However, results from GRAND show no reduction in surplus flows to the demand areas. In the cases of the EAA and NPB demand areas, the surplus flows are due to local inflows that are not controlled. In the case of ENP, the penalty value placed on surplus flows is apparently too small to cause a significant reduction in their average annual value.

The GRANDU and GRANDU2 results presented in Table 4.6 show only minor improvements over the GRAND results. Unlimited storage (GRANDU) allows greater

Table 4.6 Average annual water supply shortages/surpluses at demand nodes

Demand Node	Item	Base 2010	Grand	GrandU	GrandU2
EAA	Shortage	471.6	331.7	331.1	330.6
EAA	Surplus	486.0	486.0	486.0	486.0
ENP	Shortage	188.9	174.2	185.7	185.6
ENP	Surplus	33.6	34.8	34.4	34.6
FTMEYERS	Shortage	52.0	7.1	0.1	0.1
LOMUN	Shortage	9.7	6.9	6.7	6.7
NPB	Shortage	55.3	40.4	37.7	37.7
NPB	Surplus	42.2	42.2	42.2	42.2
SA1	Shortage	23.3	21.4	20.4	20.2
SA2	Shortage	22.8	19.5	17.7	17.7
SA3	Shortage	132.8	115.3	114.5	112.8
STLUCIE	Shortage	22.5	18.0	17.1	17.1
SEMINOLE	Shortage	22.4	15.9	15.2	15.2

regulation of estuary flows and slightly larger water supply volumes (smaller shortages) for most demand nodes. However, the GRAND and GRANDU results for ENP appear worse than those from GRAND. The increased storage and conveyance capacities allow the model to meet Lower East Coast demands more reliably, at the expense of ENP water demands.

A Closer Look

Evaluations of C&SF PRM model results from BASE 2010 and GRAND show that the alternatives considered in this report can significantly improve local water supply reliability, but they have less of an impact on water supplies to the Lower East Coast and Everglades National Park. Nonetheless, increased storage and conveyance capacity can lower the frequency of severe water shortages throughout the system.

Beyond the summary data contained in the average annual results shown above, the model results were studied in more detail to gain further insights. Deliveries for the nine demand areas were compared for each alternative to see how an alternative might change water supply reliability. Figure 4.12 is an example of the types of comparisons made. Two sets of exceedance curves are displayed comparing BASE 2010 and GRAND results. The first set of curves (Supply-Demand Ratio) illustrates the probability of meeting a given fraction of water demand in a month. These ratios are computed using the actual demand time series at each node. Since the actual demand–representing the draw on the system–is highly variable, the magnitude of shortages or surplus flows should also be considered. Thus, the second set of curves (Shortage/Surplus) represents the probability of water supply exceeding or falling short of actual monthly demand by a given amount.

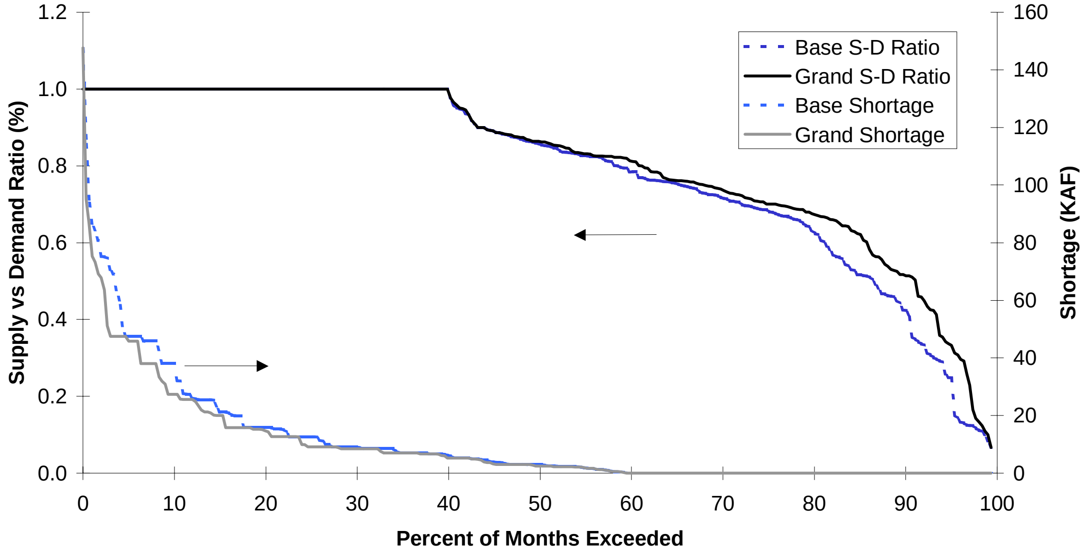

Figure 4.12 Water Supply performance indicators for Demand Area SA3

These results indicate that the proposed new projects increase water supply reliability at all demand nodes. The most significant improvement occurs at FTMEYERS where both the frequency and severity of shortages are greatly reduced. More modest reductions in the frequency and severity of shortages also occur at NPB and EAA. At the other major demand locations, however, the frequencies of shortages remain essentially the same; only reductions in the severity of shortages are seen. Since large shortages are penalized at a higher rate than small shortages, the model attempts first to decrease the severity of shortages.

From these results it is also apparent that, even with the new storage areas, water demands along the Lower East Coast (as represented in this model formulation) cannot be met reliably. Model results show water supply shortages occurring at SA1 nearly 55% of the time, SA2 nearly 30% of the time, and SA3 approximately 60% of the time. Although most of these shortages are relatively small, some are very severe. SA1 and

SA2, for instance, experience shortages as large as 25 and 40 KAF/month, respectively, while extreme shortages at SA3 exceed 140 KAF/month.

Learning from Prescribed Operations

Another benefit of using an optimization model to study potential new facilities is that the model prescribes how the new facilities should be operated. To study new facilities using a simulation model, the analyst must specify how the new facilities will be operated and how the new facilities will work with existing structures. The alternatives evaluated with C&SF PRM were formulated to take advantage of this capability.

Under the GRAND alternative, storage capacities of the proposed new areas are used to various degrees. NSTO is used only during nine periods (all with a duration of four months or less) of the historical record. In contrast, the other new storage areas are used frequently. EAASTO is more than 80% full about half of the time, and STLSTO is at least 75% full nearly half of the time. CALSTO's capacity is not used to such a great extent, but it still contains some water nearly 75% of the time.

In contrast to local analysts' expectations, prescribed storage levels in the new facilities are not highly correlated with those in existing conservation areas. NSTO is used only when LO levels are at or near the top of the desired schedule, but it is also emptied quickly to reduce evaporation losses. As a result, it is often empty even when LO levels are high. This result suggests that for most years of the historic inflows, there is adequate storage in the system to use available runoff, and additional storage capacity in the Lake Okeechobee area provides little or no benefit. Storage volumes in the other areas show only a small correlation with storage volumes in the rest of the system. One reason for the lack of correlation may be that the new areas serve primarily to regulate local inflows for local water demands and environmental needs, and the incremental inflows used in the model (i.e., delta storage values and demand adjustments) are not highly correlated throughout the system. However, optimal storage volumes in the new areas demonstrate a seasonal component similar to that of the existing areas–storage levels are generally low at the beginning of the wet season (May-September) and high at the beginning of the dry season (October-April).

Optimizing Capacities

To estimate the potential benefits of further increasing storage and conveyance capacity in the system, two C&SF PRM alternatives were run with capacity constraints relaxed. The first run, termed GRANDU, represents each new storage area with no maximum capacity. The second run, GRANDU2, represents the new storage areas and the arcs leading to and from EAASTO with no maximum capacity.

Results from the alternatives using no maximum capacities suggest that the proposed capacities for the GRAND alternative are very reasonable. The GRANDU and GRANDU2 alternative results suggest that increasing storage capacities beyond the proposed levels has little effect on water supply reliability for the LEC service areas, Everglades National Park, and the Everglades Agricultural Area.

In contrast, significant improvement is seen in water supply reliability for Ft. Meyers. Under the GRANDU case, water demands at Ft. Meyers are met virtually 100% of the time due to the increased storage capacity of CALSTO. More modest improvement is seen in water supply reliability for St. Lucie due to the increased storage capacity of STLSTO. Again, C&SF PRM is able to avoid a few severe shortages at STLUCIE by allowing less severe shortages to occur more frequently.

In general, allowing the proposed alternatives to have unlimited storage and conveyance capacity does not significantly affect the optimal operation of the rest of the system. One exception is Lake Okeechobee, which has higher storage levels under GRANDU than under GRAND. Since LO is by far the largest storage area, and it is located upstream of the rest of the system, maintaining storage levels there can significantly reduce the risk of severe water shortages. Under the GRANDU case, the increased risk of flooding is offset by providing more storage elsewhere.

System performance (in terms of water supply reliability) and storage levels in existing water conservation areas do not differ appreciably between the GRANDU and GRANDU2 cases. The one benefit of unlimited conveyance capacity to and from EAASTO is that LO levels can be maintained at even higher levels without increasing the risk of flooding (i.e., all flood flows can be released to EAASTO). Any further benefits are limited by storage capacities in the existing water conservation areas and channel capacities to the demand sites.

CONCLUSIONS

The goal of the Restudy is to determine whether or not modifications should be made to the C&SF water management system to meet environmental and water supply needs in the region. In light of the BASE 2010 results, it is apparent that modifications can significantly improve system performance. With the existing infrastructure, and assuming that hydrologic conditions in the future will be similar to those in the past, neither target flows for enhancing the Everglades nor projected water demands can be met reliably.

The proposed modifications to the system–four new storage areas and increased canal capacity in the EAA region–can provide significant benefits. C&SF PRM model results show that water supply reliability to the Ft. Meyers area improves greatly, the frequency of severe water shortages in other areas decreases slightly, and the Caloosahatchee and St. Lucie estuaries are enhanced through greater regulation of flows. However, even with the proposed modifications, severe shortages still occur at all demand sites. Particularly distressing is the severity of occasional shortages that occur at the Lower East Coast service areas and the Everglades National Park.

System performance can be improved by adding even more storage and conveyance capacity in some areas than that proposed. Notably, the reliability of water supplies to the Ft. Meyers area could be further improved by enlarging the proposed Caloosahatchee Storage Area, and the St. Lucie Estuary could benefit from increased capacity in the proposed St. Lucie Storage Area. At other locations, increased system storage and conveyance capacity can provide greater ability to hedge against infrequent but severe water supply shortages. However, the improvement in water supply reliability at many sites would be marginal, or even unobservable, in practice. Even with unlimited storage and conveyance capacities at the proposed locations, capacity constraints elsewhere in the system appear to limit the propagation of environmental and water supply benefits. Thus, model results generally indicate that the new storage areas and canals are adequately sized as proposed.

Model results also indicate some operating strategies that might improve system performance. Primarily, maintaining higher water levels in WCA1 and lower, more constant levels in WCA2A might help to meet water demands in the southern part of the system. Current operations allow water to seep northward from WCA2A, which might be wasteful if SA1 demands can be met more effectively from WCA1 alone. Also, the proposed modifications to the system appear to have a number of significant effects on the optimal operation of Lake Okeechobee. First, the Caloosahatchee Storage Area allows Ft. Meyers water demands to be met almost completely without releases from the lake. Second, the St. Lucie Storage Area allows the St. Lucie Estuary to benefit from more frequent releases from the lake, which can be diverted to the new storage area during high-flow periods and released to the estuary during low-flow periods. Finally, one combined effect of all the new storage areas may be to allow slightly higher levels in the lake to be maintained without increasing the risk of flooding.

In the future, C&SF PRM may be used in various ways to support water resource planning and management in Central and South Florida. First, the model can be used to evaluate potential benefits from other structural modifications to the system, including additional storage areas and the Water Preserve Areas concept. Second, more detailed analyses can be performed to help determine operating rules for new facilities or even adjust the operation of existing facilities. Third, given inherent conflicts in system operation, trade-off analyses can be performed by varying the relative magnitudes of penalty functions throughout the system and evaluating the resulting changes in system operation. Alternatively, economic-based penalty functions could be developed and used in the model, rather than the relative unit costs used in this study.

Based on the work done for this study, two areas for improvement in the HEC-PRM modeling environment were identified.

1. HEC-PRM should be modified to allow input of a piecewise linear area-storage relationship, and
2. HEC-PRM should be modified to allow output of marginal (dual) costs, representing the marginal change in the objective function per unit of change in arc capacity.

These changes would allow the modeling environment to be used more effectively in a wide range of cases.

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Chapter 5:
Examples of Theory in Practice:
Failures, Successes, Gaps, and Directions

INTRODUCTION

This chapter attempts to reconcile theories of policymaking and the use of technical information with experience from involvement in several technical studies related to water management debates. There seems to be widespread sentiment among analysts and modelers that water policy outcomes would be better if “decision makers” would pay more attention to technical studies and use more quantitative information when making decisions about policy. Some professional analysts point to the length and cost of policy debates that result in years of stalemate while serious problems continue unresolved as a problem with policymaking that needs to be improved. Examples of these costly stalemate situations often involve conflicts over the decline of species (such as salmon on the west coast) and how to balance the species’ protection and restoration with potentially large economic costs of restorative efforts.

Other criticisms of policy-making processes involve how funds are spent. Some policy participants argue that if the decision making process is not based on sound science, expenditures can be inefficient and even ineffectual. People advocating the use of more technical information to make decisions believe that resulting policy outcomes could be better (in terms of reasonableness, success in solving a problem such as species recovery, durability, economic efficiency, and general acceptance) than decisions made primarily based on "politics". There seems to be widespread agreement that policy-making processes could be improved. The question explored in this chapter is: Are there ways professional analysts can make technical information they produce more useful for producing sound policy outcomes?

EXPERIENCES AND OBSERVATIONS

This section summarizes some experiences from participating in several large-scale and multi-agency water policy debates (Table 5.1). For each project, some thoughts are offered describing the policy context in which the study occurred, problems faced, observations of how results were used, and perceived impacts of the technical studies.

Columbia River System

This particular study was third in series of studies commissioned by the Corps to help with the System Operation Review of the Columbia River System (USACE 1995; USACE 1991; USACE 1993). This phase was primarily a research-oriented effort to explore the potential of applying an optimization model to a large, multiple purpose reservoir system to improve operating rules. While the North Pacific District partially funded the effort and participated by providing information and data, there was little local interest in the results.

Most of the problems faced during this study involved data -- both in acquiring the data needed to perform the study and then organizing, processing and managing the masses of input and output data. Much of the effort (and funding) expended to complete this analysis was directed towards acquiring and manipulating data.

Table 5.1 Recent Technical Studies Contributing to Experiences and Observations

Project	Policy Context
Application of optimization model (HEC-PRM) to Columbia River System to Explore Changes in System Operation	The Corps' North Pacific Division and the Real-Time Water Control Research and Development Program funded the Hydrologic Engineering Center (HEC) to complement a system operation review (SOR) of the Columbia River System by US Army Corps of Engineers, US Bureau of Reclamation, and Bonneville Power Administration.
Application of optimization model (HEC-PRM) and simulation model to Bill Williams River in Arizona	The Corps' Los Angeles District funded HEC to help in technical studies intended to help resolve conflict over Bill Williams River and Alamo Reservoir in Arizona.
Application of stochastic simulation model to Bill Williams River in Arizona	The Corps' Los Angeles District funded HEC to conduct technical studies intended to help explore alternative reservoir operations designed to manage conflicts between listed species on the Bill Williams River system.
Application of optimization model (HEC-PRM) to central and southern Florida system	The Corps' Jacksonville District and the South Florida Water Management District funded HEC to develop an optimization model to support technical analysis involved in the "Restudy" being conducted to help resolve conflicts in central and southern Florida.
Development of analysis framework to evaluate financial incentives for private investment in California water infrastructure (CALVIN)	California Resources Agency and CALFED Bay Delta Program funded University of California, Davis to develop methodology and analytical tools to explore the role of private finance in solution of California's water problems.
CALFED Bay Delta Program Water Management Strategy Evaluation Framework	The CALFED Bay-Delta Program, (a group of federal and California agencies formed to help address problems related to the San Francisco Bay – Delta), worked with stakeholders and consultants to formulate a technical analysis methodology to help evaluate proposed water management alternatives.

Results of the study successfully demonstrated that application of large-scale, economically based optimization models can be useful for identifying potential improvements in reservoir system operation rules. As mentioned above, there seemed to be little interest from NPD in applying these results directly. Personnel from the North Pacific Division (NPD) were busy conducting their own simulation-based modeling to support the SOR. Several of the senior operations personnel in NPD seemed to distrust the credibility of optimization models and resisted their application.

The impacts of this study were to demonstrate the feasibility of this type of analysis and to highlight the need for better data management techniques and tools. During the course of the study, small improvements were made to the HEC-PRM modeling software. Some of the results of the analysis suggested promising ideas to explore further with detailed simulation modeling.

Bill Williams River, Arizona

This work stemmed from an attempt to resolve years of conflict among resource managers responsible for resources on the Bill Williams River Corridor in Arizona (BWRCTC 1994). Two studies were done for the USACE Los Angeles District, a major participant in efforts to resolve conflicts involving Alamo Reservoir. The first study evaluated how a combined optimization – simulation modeling approach would compare to the interactive simulation exercise that had already been conducted (USACE 1999). The second study provided technical input on issues not addressed by the Bill Williams River Corridor Technical Committee earlier due to the complexity in evaluating the issues (USACE 1998b).

Technical Methods and Advocacy Interaction

A committee was appointed by the agencies involved in conflicts surrounding Alamo Reservoir and the Bill Williams River to find a way to mitigate the problems being experienced (BWRCTC 1994). Participants of the Bill Williams River Corridor Technical Committee engaged in a process to identify and explicitly define objectives of the different interests involved such as fisheries, endangered species protection, flood control, etc. Through frequent dialog and interchange, the different advocacy groups gained an understanding of others' objectives and how those objectives related to their own. After each group's objectives were defined, the Los Angeles District developed a reservoir simulation model to allow the committee members to formulate and evaluate different operating scenarios. Based on the specified objectives and numerous model simulations, the committee was able to agree upon a new set of operational rules that their respective agencies felt would be an improvement over the existing operating rules.

The policy debate surrounding the Bill Williams River conflict is an example of how different participants can engage in policy-oriented learning (Sabatier and Jenkins-Smith 1993) and initiate policy changes perceived to be beneficial by all involved. Also, the approach used by the participants was to evaluate incremental changes to the existing operations rules, is consistent with Lindblom's (1959, 1979) hypothesis that partisan groups advocating different positions can produce sound policy changes through incremental changes to what they know.

After an agreement was reached, participants acknowledged that the process of explicitly defining objectives and studying the limitations of the physical system helped them to find a solution that was agreeable to all. This is a case where technical information played an integral role in the debate and resulted in a reasoned approach to settling conflict. However, the mutual learning process that led to a new operating agreement took place over five years, and the process to legally change the operating policy of Alamo Reservoir is expected to take several more years. This time line is consistent with observations by Weiss (1979a, 1979b) and others (Lindblom and

Woodhouse 1993, Sabatier and Jenkins-Smith 1993). Participants in the BWRCTC expected they would be able to reach agreement much sooner (in one to one and one half years). This example is consistent with the theoretical assessment that even in a successful application of technical information to resolve conflict, the process takes many years to effect policy change. Furthermore, the success of technical information leading to an agreement for this conflict is probably not indicative of other resource conflicts. In this event, by proposing incremental changes to existing operations, a new operational strategy was found that literally made everyone involved in the conflict better off than they were before the change. This situation is not likely to occur in many resource conflicts.

Comparing Modeling Methods

After the simulation studies had been performed with direct input of the technical committee, an independent study was conducted with an optimization model (HEC-PRM) using objectives the technical committee had compiled earlier. The purpose of the study was to illustrate how optimization and simulation models could be used together and to determine if the combined modeling approach could yield a better result than the one agreed upon by the BWRCTC using the simulation by enumeration process. Results from the combined optimization and simulation process confirmed that the BWRCTC had reached a sound agreement. No alternatives could be found using the combined optimization and simulation modeling approach that satisfied the multiple objectives better than the plan the technical committee had developed (USACE 1999).

This independent analysis confirming the committee's findings provided more confidence in the decision to move forward to officially change the operating rules for

Alamo Reservoir. Beyond bolstering the confidence of the participants, application of the combined approach helped expose several members involved in the process to a method they were not familiar with that could be helpful to them in the future.

Bald Eagles vs. Southwestern Willow Flycatchers

Shortly after the BWRCTC reached an agreed upon new operating strategy, some unexpected events threatened to disrupt the plan before it was implemented. Several episodes of high inflows into Alamo Reservoir threatened bald eagle nests and fledglings due to rapid rises in Alamo Reservoir water levels. This threat to an endangered species introduced a new operating dilemma that had not been considered explicitly in the earlier analysis. This is an example of how events outside of the control of the policy participants can heavily influence policy outcomes (Kingdon 1984; Iyengar and Kinder 1987).

Chapter 3 outlines how technical information was developed to help characterize potential impacts to eagle nesting and other objectives by explicitly considering the stochastic nature of eagle nesting behavior (USACE 1998b). Again, one of the problems faced during this technical study was the availability of important data. Data regarding eagle nesting behavior was scarce, and information about potential nesting sites was even more limited. Nonetheless, LA District personnel felt that the results of this analysis provided them valuable insights to the likely interaction between operating the reservoir to protect bald eagles and resulting impacts on other authorized purposes.

The Los Angeles District shared this data with the US Fish and Wildlife Service to explore potential system interactions based on different operational choices. Implementation of the earlier BWRCTC operating agreement is proceeding with language to allow for adjustments to respond to future conditions such as this conflict between listed species.

Central and Southern Florida

This case illustrates how different analytical approaches can be used to promote learning among other analysts, and then distilled before communicating to "decision makers". As outlined in Chapter 4, the development and application of an optimization model for the central and southern Florida system was intended to help the Jacksonville District and South Florida Water Management District (SFWMD) modelers.

After overcoming technical challenges experienced representing the Florida system with a network flow optimization model, a model was successfully developed to help evaluate potential changes to the system to improve performance. Results from this study confirmed results from previous studies regarding the size, location, and expected benefits of new surface storage areas. Furthermore, an optimization model was developed that can be used by the Jacksonville District and SFWMD in future analyses.

This study benefited from improved data management tools that had been developed in response to difficulties managing data from the Columbia and Bill Williams River studies. Nonetheless, data management and manipulation was still one of the biggest problems with this study. Analysis of the large amounts of data generated for each model run required preparation of custom post-processing tools to evaluate and compare model results.

The Jacksonville District and the South Florida Water Management District used the results from this analysis to compare to other, more traditional studies that had been conducted. The independent analysis using an optimization model served to confirm that the alternatives being proposed as part of the Restudy were technically sound (USACE 1998a).

CALVIN

Funding for this work arose from a high-level policymaker (California's Secretary of Resources Douglas Wheeler) because he recognized the lack of directly applicable tools to evaluate economic and financial implications of very expensive alternatives being considered to address California's water problems. The Secretary's initiative to start this research work confirms the observation that policymakers recognize the need to continue to learn more about the systems they are responsible for governing (Sabatier and Jenkins-Smith 1993; Lindblom and Woodhouse 1993; Bryner 1992).

Numerous theoretical challenges had to be addressed to formulate the CALVIN model, but without a doubt, the biggest problems experienced during the CALVIN project involved data. The CALVIN model is a statewide optimization model of the entire inter-tied water management system in California (Howitt et al. 1998). This effort is the first to construct an economically driven optimization model representing surface and groundwater resources across the entire state. Theoretical development for this model and the adaptation and development of software necessary to run this model took about one year. In contrast, the collection and reconciliation of necessary input data to make the model meaningful has taken over three years -- and remains incomplete. The data gathered includes only structural, hydrologic, and economic information. Biological and ecological data were not included explicitly because they do not exist. Data that exist are held by numerous agencies in incompatible formats. There are regions in the state for which some of this data has never been compiled in a systematic form suitable for modeling. Differing methods between agencies have resulted in apparently similar sets of data being irreconcilable.

In spite of the data difficulties, this project has had a number of successes. Formulation of this tool has generated sizeable interest and enthusiasm among other analysts and policy participants in California. Interactions with the policy advisory committee exposed policy participants to a new application of technology they found appealing for future use. The capability of this economically based statewide model is seen as a beneficial tool to help evaluate complex water management strategy proposals likely to be debated considered over the next twenty or more years in California (Newlin 2000).

Due to the difficulty managing data experienced in previous projects and the sheer magnitude of data involved to formulate this model, data management received a high degree of priority and attention from the outset. Significant resources have been devoted to organize, document, and manage the input and output of data for this model. Some of these new ideas regarding data management have been used to help raise awareness among other technical groups that data management needs more attention. The long lead times and institutional efforts needed to organize and reconcile data for flexible system models is a major policy-related realization of this work.

CALFED Water Management Strategy Evaluation Framework

Work to develop the Water Management Strategy Evaluation Framework occurred as part of the CALFED Bay Delta Program (www.calfed.ca.gov). CALFED has provided a forum to promote stakeholder and interagency interaction to help reduce the conflicts surrounding the San Francisco Bay Delta system. This technical work was (and is being) done to develop a quantitative method for systematically evaluating proposed water management strategies to meet CALFED objectives.

This project has involved much more direct interaction with policy-making participants than the projects described above. Throughout the process, there has been a large demand for technical information such as hydrology, delivery quantities and reliability and economic affects to urban and agricultural regions. Different policy participants (such as stakeholders, agency staff and management, and political officials) have wanted different forms and level of technical information. These attempts to produce quantitative estimates of impacts for proposed policy changes has been closely tied to the schedule and time line of the political process.

Problems faced during this work have been numerous. The high level of stakeholder involvement has led to considerable difficulty identifying and agreeing upon what the technical analysis should address. Another significant problem has been the disparate schedules between the political process and policy participants' request for technical information and the professional analysts' ability to provide that data. In many cases over the past two years, analysts simply have not been able to produce the data requested in the time allowed to produce it. Again, a large factor in the inability to produce the desired technical information involves data.

The types of information being requested include estimates of changes in water quantity, water quality, economic, and environmental performance between alternatives. No models currently exist that can predict all of these elements in an integrated fashion. As a result, a number of models are being used in sequence to predict responses to changes in the water management system. Since these models were not designed to work together, linking them has been extremely difficult. Sharing data between the models has been very cumbersome and labor intensive. As a result, the process has been highly prone to errors and has caused numerous delays in producing desired results.

Results that have been produced have been applied in various ways, consistent with the “Uses of Analysis” section in Chapter 2. The most prominent use of this data falls under the category of *political ammunition*. Many of the policy participants have a defined agenda and look for data to support their arguments and actively try to discredit anything that does not support their position. This type of behavior produces little if any policy-oriented learning. Furthermore, some stakeholders are attempting to use technical information (or the purported lack of it) to *delay* changes in policy. Fortunately, there has also been some *interactive* use of technical information where policy participants genuinely seek to learn about the system to help find a workable compromise. This interactive application of technical information is the primary form of use the water management strategy evaluation framework tries to support.

The impacts of the CALFED Water Management Strategy Evaluation Framework technical work are difficult to quantify at this point. Since the most prominent use of data to date has been as political ammunition, most of the analysis has been used as a weapon to hurl at opponents with little obvious benefit. Perhaps for those willing to engage in the interactive use of the technical information there has been some increase in the general knowledge regarding the system and its interactions. Hopefully, this type of use eventually can promote more reasoned debate over the long term as the CALFED activities move into implementation.

THEORY AND PRACTICE

As evidenced in the engineering literature, analysts periodically attempt to evaluate how successful their efforts are in influencing policy outcomes (Liebman 1976; Loucks, et al. 1985; Rogers and Fiering 1986; Loucks 1992). Some of these authors have offered suggestions to make our contributions toward development of sound resource policy development more effective (Loucks et al. 1985; Loucks 1992). This section attempts to reconcile recent experiences with the theories explored in Chapter 2.

Demand for Technical Information

Experiences related to the projects described above indicate that policy-making participants are demanding, and will likely continue to demand more and more technical information regarding proposed policy changes. As seen in some of the studies described above, different groups will use the information in different ways. While different groups have different intents for the data being demanded, one frequent theme is that the data professional analysts are providing often is not consistent with what policymakers want and need to help them influence policymaking. This apparent mismatch is consistent with earlier observations by others (Weiss 1977a, 1977b; Lindblom and Cohen 1979; Loucks et al. 1985; Lindblom and Woodhouse 1993).

If professional analysts want to be more effective in contributing toward sound policy outputs, one area to target is reducing the mismatch between what policy-making participants ask for and what we deliver. Based on my experiences, most policy-making participants appear to look for four characteristics in technical information when deciding if it is useful (listed in order of preference):

1. *Simplicity*
2. *Relevance*
3. *Generality*
4. *Credibility*

Simplicity

This quality seems to be the first (and paramount) hurdle. People that participate in policy-making activities are always distracted and pressed for time. Many policy-making participants tend to communicate at the level of sound bites. Due to time pressures and scheduling constraints, it is common for analysts to be asked to present the results from months of work to a group of policymakers in fifteen to twenty minutes. Beyond the short amount of time allotted to communicate results, the presentation is often sandwiched between other, maybe very different agenda items. The requirement to distill technical information so radically is a great source of frustration for many professional analysts. However, if policymakers cannot understand the analyst's message under these conditions (and subsequently convey it to others) then they typically cannot (or will not) use the information. "People would rather live with a problem they cannot solve than accept a solution they cannot understand." (Woolsey and Swanson 1975)

This tension between the groups is consistent with the idea of differing types of knowledge (Loucks et al. 1985; Lindblom and Cohen 1979). Analysts interested in supplying useful data to policymakers could reduce their frustration by realizing that knowledge needed for understanding is not necessarily the same as knowledge needed for making decisions, and adjusting their presentations accordingly. The apparent need for simplicity also supports Lindblom's (1959, 1979) assertion that policymakers tend to rely heavily on incremental departures from existing or recent experiences, because the policymaker draws heavily on their existing knowledge about the system in question to project how the system might respond under a slightly different situation.

Relevance

If available technical information passes the simplicity requirement, then the next question seems to be "What's in it for me?" Again, policy-making participants tend to be very busy and are mindful of their limited resources. They must be strategic in how they use their resources to be successful. If it is not readily apparent how the data presented can help them further their objectives in the near term, they have little motivation to pay attention. This lack of perceived relevance can be readily observed in meetings with policymakers by noting how many policymakers leave the room or table to engage in side conversations or make phone calls while technical presentations are being made.

Generality

If information passes the simplicity and relevance test, policymakers want information that they can apply widely. They want information that can be readily extrapolated to other situations not analyzed explicitly. This type of information, if made available is much more valuable in a dynamic and quickly shifting policy-making context than detailed information subject to a host of limitations that prevents extrapolation to other situations readily.

For instance, most policy participants prefer information such as “Increasing either surface or groundwater storage north of the delta can reduce salinity levels in the delta. However, all things equal, additional surface storage provides more reduction (on the order of 3 to 1 for storages between 500 TAF and 1.8 MAF).” as opposed to conclusions such as “Alternative A (with 500 TAF of additional surface storage north of the delta) provides a 3% reduction (on average) in salinity in the delta, while Alternative B (with 500 TAF of additional groundwater storage north of the delta) only provides a 1% reduction in delta salinity.”

Credibility

Finally, if information meets the three criteria above, the policymaker assesses how credible the information is. The level of credibility required seems to vary depending on how the policymaker intends to use the data. For instance, if the data is intended for political ammunition or delay, the credibility threshold often seems quite low. In fact, in these cases the volume of information sometimes seems more important. It may be strategically desirable to present large amounts of technical information supporting your view (or challenging your opponent’s view) and leave your opponent to expend resources trying to refute or discredit the information you present.

On the other hand, if a policy participant has chosen to engage in an interactive use of technical information intended to promote policy oriented learning, the participant seems very concerned about the credibility of this information. Sabatier and Jenkins-Smith (1993) argue that this is because people resist changing their beliefs and most often require multiple sources of independently derived information produced over time to cause them to change their views (Weiss 1977b; Lindblom and Cohen 1979).

Assessing the Gaps

Why do widespread feelings of discontent about the process from both policymakers and professional analysts persist? Why is it so difficult to produce timely technical information that meet the four criteria outlined above?

In an attempt to understand these processes and explain them, I offer a cartoon model that provides a caricature of the interaction between analysts and decision makers. In this model there exists a tall brick wall. From one side, decision makers throw bags of money over the wall to a group of analysts on the other side. The decision makers then claim credit for contributing to the advancement of understanding of the problem – and then promptly forget what the problem was when they threw the money over the wall. On the other side, the analysts then wrestle over the pile of money, debating heatedly among themselves about how "best" to spend it. Then, after months (or years), the analysts proudly heft their resulting product – a large technical report – over the same brick wall and eagerly await news that their insightful findings (spelled out in magnificent detail in their report) directly resulted in a widely heralded policy outcome. Unfortunately, in this model, the analysts rarely hear anything back from the decision makers unless their report happens to land forcefully on a decision maker's toes on its way down after being tossed over the wall.

While extreme, this caricature captures some of the reasons for the apparent mismatch in the technical information routinely produced and the information desired by policy-making participants.

Divided We Stand

Why are most analysts on one side of the wall and most policymakers on the other? For one reason, technical analysts and "decision makers" tend to be very different. Other authors, both engineers and political scientists, have observed this phenomenon. As discussed in Chapter 2 these apparent differences and the resulting communication difficulties are referred to as a cultural gap (Sabatier and Jenkins-Smith 1993; Dunn 1980; Webber 1983; Loucks et al. 1985).

This cultural gap is evidenced in many ways. Illustrations of this gap frequently occur at technical conferences. At some point during the conference at least one, and sometimes several, professional analyst(s) stand up and lament the shocking absence of decision makers in these technical presentations geared towards making better policy decisions. The outspoken analysts seem perplexed as to why no decision makers recognized the tremendous benefits they would obtain by listening to detailed technical discussions about some new mathematical solution algorithm or spiffy new model. Yet, if you ask the same audience whether they have ever participated in a policy conference, most if them would answer no.

Another example of this one-sided perspective is that professional analysts often believe decision makers fail in solving water problems because the decision makers have a very limited (and perhaps "incorrect") understanding of the physical systems they attempt to govern. While this may be true, many analysts do not recognize or acknowledge their own primitive understanding of the policy-making processes they purport to improve.

Hitting the Wall

Why does the wall exist and where does it come from? Primarily, the wall exists due to the difficulty in producing the information policy-making participants want and need. Even if there existed perfect understanding and communication between the two groups, there are very real hurdles that hinder the generation of this data. However, given that the wall exists, the two groups tend to maintain the wall rather than actively look for ways to tear it down. After all, drawing from common knowledge both groups know that "good fences make good neighbors."

For instance, professional analysts tend to work in institutions with very different incentive structures than politicians. One of the safest strategies for an agency analyst to rise to middle or upper-middle agency service is *not* to influence policy. If an analyst wants to reduce the risk of political retaliation, they want to avoid identifying closely with any particular advocacy group since the political groups in power are subject to change (with each election cycle) many times during an analysts career. This motivates keeping the wall.

Conversely, politicians have little incentive to pay much attention to technical details since time spent studying technical details diverts them from other, perhaps more productive political activities. While policymakers recognize the need for continued learning, they rarely invest heavily in learning detailed technical information, but rather rely on their common knowledge and its gradual evolution through sedimentation of new ideas and concepts (Weiss 1977b; Lindblom and Cohen 1979).

Furthermore, professional analysts tend to use decidedly different criteria when deciding what to work on or how to approach "solving" problems. For the most part, professional analysts want to work on larger, more sophisticated, more mathematically elegant models. Analysts are more interested in detail, numerical precision, and computational speed – not simplicity. It seems that most analysts really are not interested in working on the things decision makers are asking for. These differences in interests are partially why the cultural gap exists, and also contributes to maintaining the wall.

Beyond the reasons for segregation, the source of the wall arises from other difficulties analysts face in providing what the policymakers ask for. In some cases, professional analysts are not producing more simple, relevant, and general information because we do not know how. Many analysts find it easier (or at least possible) to build bigger, more complex models than to create models of complex processes that can help policymakers directly. We have found that through persistence and hard work we can expand existing or former approaches to produce impressive and elegant models (at least to other professional analysts).

In some sense, what the policymakers want is antagonistic. It is very difficult to formulate models that are both simple and general. Normally, to derive a simple model of a complex system, the model must be designed with a very narrow focus. Conversely, if generality is the object, analysts typically must include high degrees of complexity. Reconciling these divergent trends is extremely difficult. Left with the choice of struggling to produce something a decision maker can use or embarking on a project more in line with our interests and more likely to build respect among our peers, the choice tends towards complexity. In keeping with this trend, few examples exist in our literature that point to development of the tools decision makers seem to want.

Where Did You Get That?

Beyond the cultural and conceptual difficulties mentioned above, data is the most limiting factor in many technical studies. Often, the data needed for technical studies is difficult, if not impossible to obtain in a reasonable time frame. The difficulty obtaining real data may explain why most published technical papers do not use actual data, but rather rely on hypothetical problems.

The CALVIN project and the CALFED Water Management Strategy Evaluation Framework effort described above highlight the severity of data related problems. Even for much smaller studies, models and their inputs are typically not well documented or organized. Typically, multitudes of model runs (and their resulting data sets) are managed in an ad hoc manner. These data sets are rarely archived effectively so they are often lost within a few years, if not sooner. The reason for this is likely far more complex than mere incompetence. Organization of technical activities lags well behind contemporary problems and proposed solutions. Problems encountered with data are currently one of the biggest detractors from perceived credibility of the technical information we generate.

REFLECTIONS AND DIRECTIONS

Are there ways to bridge the gap and reduce the disparity between what policymakers want and what analysts can provide? Perhaps, but first we should recognize that technical information will rarely have a direct impact on significant policy outcomes. Due to the nature of policy-making processes, an analyst and the information she can produce play only a very small part in the evolution of water policy. Even a disproportionately large influence would be small, and likely episodic. Actually, because of the diversity of influences and diverse veto power, most individual policymakers also play a very small part (Lindblom and Woodhouse 1993; Sabatier and Jenkins-Smith 1993). What can a single interest group leader, legislator, governor, or even the president really do? The processes that lead to formation and constant evolution of policy are well beyond the direct control of any individual. Nonetheless, while recognizing this context, technical information can be useful and is direly needed in policy-making efforts.

Reducing the Mismatch

The simple caricature offered in this chapter offers two symbols contributing to the mismatch between technical information produced and technical information desired to influence policymaking: a wall (built largely from technical and communications difficulties), and segregation of policymakers and professional analysts. To reduce the mismatch, it seems reasonable to find ways to reduce the negative impacts of both contributors. As seen above, the presence of the wall and segregation tend to enforce one another. Therefore it is difficult to address one without considering the other.

Weakening the Wall

Presuming sufficient motivation exists on both sides, there are ways to help mitigate the difficulties in generating and applying technical information in policymaking. Due to the enormous difficulty of generating this information, the obstacles likely will never be eliminated completely. However, with patience, persistence, and opportunities, analysts (with support of policymakers) can take tangible steps to make the exchange of technical information easier. Specific recommendations are offered in the next section.

Crossing the Divide

Efforts to overcome technical difficulties in producing and delivering relevant and timely technical information would likely be more fruitful by establishing better communication between professional analysts and policymakers. If more members of each group could interact more effectively, the information mismatch could probably be reduced simply through better mutual understanding. One small step towards improving mutual understanding would be for analysts to learn more about policy-making processes.

Realistically, I do not expect to see great strides in this area any time soon. People choose to be analysts or policymakers based largely on their interests and aptitudes. There is little hope that significant numbers of either group will suddenly develop an interest to cross the cultural gap (and desegregate). Fortunately, a few individuals exist that are genuinely interested in both sides. Loucks et al. (1985) referred to these individuals as policy brokers: individuals capable of understanding the technical details well enough to effectively communicate with analysts and yet willing (and able) to recognize that social problems do not require understanding to be ameliorated. Perhaps universities can encourage development of those inclined to serve as policy brokers by offering and encouraging graduate education programs emphasizing and encouraging serious study outside the traditional analytical disciplines.

Recommendations

In this chapter, theory and experience concur -- providing and applying technical information to improve policy outcomes is very difficult. Nonetheless, the need is great. Many policymakers apparently recognize the need for balancing knowledge with power. This recognition is reflected in the increasing demand (and subsequent funding) for technical information related to water management policy debates. Yet, both professional analysts and policymakers have expressed dissatisfaction related to the use of technical information in recent water policy-making efforts.

For analysts interested in providing more useful technical information to policymakers I recommend the following:

1. Manage thy data
2. Think long term
3. Understand more -- explain less
4. Learn how to select a good bottle of wine with dinner

Manage thy Data

I believe improved data management can provide the most tangible improvements in our capability to provide the types of information requested by policymakers in the shortest amount of time. Collecting, organizing, evaluating, sharing, and presenting data is central to every technical study. Limitations in existing data management practices and capabilities make the goal of providing timely and relevant technical information to policymakers increasingly difficult.

Historically, data management typically has been disdained; the process is laborious, costly, and frankly not very appealing. Most analysts and policymakers simply are not interested in the mechanics of managing data. Nonetheless, as seen in the technical studies presented in this chapter, data is always necessary to analyze and understand a system quantitatively. Lack of data, or inability to access previously collected data hinders development of our understanding about the problems and related systems they affect. Useful data can almost always lead to better understanding – even if the system cannot be modeled. The data can always be used to establish baseline conditions and monitor the effects of proposed policy actions. In fact, in many cases observed data are more likely to satisfy policymakers' needs than models.

As a result, professional analysts should collectively strive to establish sound data sets that can be easily scrutinized, shared, and updated. With the advent and rapid application of the Internet and corresponding improvements in database software, technology currently exists to make this possible. However, to obtain and effectively manage the data needed we must go beyond technology. We need to apply some systematic and concerted thinking to modify the processes used to gather, compile, archive and disseminate data. Data management can be improved by reevaluating the following:

- Identify potential uses for data being gathered and stored – the uses should go much further than publishing in a paper report. All data should be gathered with the expectation that it could be easily used for some formal analysis such as modeling or data evaluation.
- Define a data structure and standards to facilitate data interchange between institutions, people, and models – Examples of this type of data structure and standards can be found in the manufacturing industry. To be efficient in production, the industry has developed a common and clearly defined data standard that all participants can adhere to. This allows different companies, with different internal cultures, different software and different technology freely share information reliably to work together.

- Make data widely accessible in electronic form – There are many examples of how this can be done in the e-commerce industry. This type of accessibility can facility the revision of data sets by allowing widespread scrutiny and correspondingly can help improve long-term credibility.
- Include assumptions and other data documentation with the data – With the proliferation of data and hopeful widespread access and application of this data, it is increasingly important to describe what the data is and where it came from. This should include information such as source of data, contact personnel, level of confidence in the data, and any assumptions used in generating the data.
- Automate data collection – If a well-defined data structure is developed, agencies of all different levels of government can cost effectively gather and store data automatically using remote sensing and other data gathering technologies. In fact many agencies already are. However, the organization and clear data standards are necessary to facilitate compilation and reconciliation of this data at different scales.

Think Long Term

In addition to better data management, professional analysts need to adopt a decidedly long-term perspective. Recent experiences with CALFED again demonstrated that technical analyses of complex natural systems frequently could not produce results on the same time scale as the decision makers must operate to provide "answers" to the current questions. Weiss (1977b) and others have concluded that quantitative efforts will most likely be successful through gradual sedimentation of ideas and eventual shaping of common knowledge. This long-term perspective should include long-term tool development geared toward promoting general learning, not just to crisis management.

Large changes in water management have never come quickly. Nonetheless, much of the effort of professional analysts is focused on short-term work. This is understandable in a policy context, because most policy participants tend to focus on current events and the next likely crisis. However, because many analysts are separated to some degree from the day-to-day variations in political attention, they have opportunities over their careers to promote and foster a long-term perspective. This long-term perspective would likely cause people to think differently about how to develop analytical tools and data management infrastructure than a purely shortsighted perspective. In fact, over ten to twenty years, farsighted development will likely improve the profession's ability to respond to short-term demands more effectively than maintaining the current reactive approach. In particular, a long-term perspective is needed to manage and reconcile data.

Understand More – Explain Less

The apparent antagonism between providing simplicity and generality can be resolved (at least partially) by what we do with models and their results. We can strive to understand more and yet explain less. As discussed earlier, analysts tend to develop and work with increasingly more detailed and complex models. Then when we try to share that level of detail, we become frustrated when policymakers do not appreciate our accomplishments or use our results. While the increasingly detailed and complex models are probably necessary to further our limited understanding of natural, social, and economic systems -- we cannot stop there. We need to take the harder step to use what we learn, without trying to force the detail onto the policymakers, and develop robust, general and simple ways to communicate what we learn that can improve the general level of understandings of cause and effect within the system where policy changes are being sought.

For example, how much do you need to know to operate an automobile? People operate automobiles without really understanding how they work. They rely on knowledge such as pushing the accelerator in a car will cause the car to speed up and depressing the brake pedal will cause a car to slow down. Most of us do not really understand how or why this happens. Most people do not feel the need to know much more detail. Most of us recognize that there are limits to the general statement of cause and effect. For example, the car will not move in response to pushing the accelerator if the engine has not been started and the car may not slow down if there is insufficient brake fluid. Most of us recognize there are limitations with all general assertions, but we deal with the exceptions as they become important to us and rely on other experts to help us deal with these exceptions when we cannot. This is the way we should approach communicating what we learn from our complex technical analyses to most policymakers until they ask for more.

Learn How to Select a Good Bottle of Wine With Dinner

Finally, we need to branch out. Solutions to social problems are not based on the solution of a mathematical problem, no matter how elegant. We must recognize the policy-making process for what it is: a messy, unpredictable process full of conflict geared toward attacking problems, not understanding them. In the end, policymaking is primarily about people and relationships. Based on experience, most analysts could benefit from improved social and interpersonal skills if they want to help improve policy outcomes.

If we want to affect policy outcomes, we most likely will have to abandon the supposed role of neutral technician. If we want to promote reasoned persuasion as an alternative to pure power politics, we must find ways to build tools that help advocacy groups learn about the problems they are attacking. To help improve the odds of success of policy outcomes, we must be patient, persistent and prepared to exploit opportunities to raise the quality and level of common knowledge about water systems. This gradual evolution of common knowledge and facilitation of advocacy group learning are the most likely avenues for technical information to improve policy outcomes.

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Chapter 6:

Summary and Conclusions

Growing populations and changing social values have increased the potential for conflict over natural resources. Many people across the country are discontent with the way water and environmental resources are being managed. People unsatisfied with how the resources are being managed are pressing for changes in public policy. Public policy for water and environmental resources must address high degrees of interaction between physical, social, ecological, and economic systems. The desire to change policy and the difficulty of finding ways to resolve the conflicts have increased demand for technical information regarding these problems and potential solutions. Unfortunately, the available technical information often does not meet the needs of policymakers.

This thesis explores interactions between technical information and policymaking to determine if professional analysts can provide technical information more useful in helping craft sound policy outcomes. Specifically, the thesis:

- Summarizes a theoretical framework for thinking about policymaking
- Reviews different ways technical information is used in policy-making processes
- Describes the use of a Monte Carlo simulation model to help decision makers consider uncertainty when trying to resolve conflict between bald eagles and other listed species in Arizona
- Describes the development and application of a network flow optimization model to the central and southern Florida water management system to provide an

independent assessment of potential system improvements being studied by other analysts

- Compares practical experiences with theories from the literature
- Offers suggestions for professional analysts to provide more useful information to policymakers

Papers in the engineering literature presenting how analytical techniques can be applied to help evaluate policy-related issues tend to present a very simplified view of policymaking. In many cases, the papers rely on identifying decision makers with well-defined objectives making discrete and measurable decisions. This simplification is often necessary to try to model ‘decision making’ mathematically, but also points to some of the inherent limitations of trying to use analysis to solve social problems such as water management.

The political science literature offers a different view of policymaking. Policymaking is described as a complex set of processes involving a multitude of participants trying to reach agreement (not necessarily understanding), subject to influence from many factors, causing policy to evolve rather than be decided upon. According to this view, technical information definitely plays a role in policymaking, but rarely as a direct input to a solution. Technical information can be used in many different ways as part of the advocacy process. Perhaps the most significant impact of technical information is the gradual evolution of common knowledge over many years. While most technical studies tend to be funded as short-term projects, professional analysts are likely to have greater success influencing policy outcomes if they develop a long-term perspective. Rather than attempt to solve social problems via technical analysis, analysts may be able to adapt technical studies and information to be more effective in policy-making activities by:

- Emphasizing plausibility over elegance
- Stimulating competition of ideas
- Supporting incremental learning
- Developing and providing tools and studies geared toward improving quality of ordinary knowledge

Logistically, one aspect of technical analysis greatly needing improvement is data management. Data management has historically received less attention than analytical techniques or model development. However, the lack of readily accessible data hinders analysts' ability to further our understanding about water problems and the systems they affect. Thanks to the recent expansion of data management technology, closely associated with the rapid rise of the Internet, capabilities to manage large amounts of diverse data have never been better. Professional analysts should lead efforts to promote better data gathering and distribution processes within the agencies responsible for managing natural resources. Development of an industry-wide data standard, similar to that used in manufacturing, is needed to facilitate sharing of data between groups for different purposes.

Another area that obviously needs improvement is communication between analysts and policymakers. Analysts are faced with the challenge of developing better understanding of complex processes and communicating this understanding in a simple form to others. This effort will likely require continued development and application of complex models. Nonetheless, analysts should recognize that the complex models are not useful to policymakers. To be effective, analysts must go beyond the models themselves and develop understanding about the systems being modeled and find ways to communicate the knowledge gained as simple and general observations to people involved in policymaking.

Finally, analysts can benefit by recognizing that solutions to social problems will never be based on solutions to mathematical problems, no matter how elegant. In fact, 'solving' social problems does not require understanding. Analysts can likely become more effective by recognizing that policymaking is a messy, unpredictable process full of conflict, geared toward attacking problems – not understanding them. Ultimately, policymaking is about people and relationships. If analysts want to be more successful in contributing to sound policy outcomes, they need to offer more than technical information. A policymaker's perception of an analyst can impact their reaction to the information provided as much or more than the content of that information. An analyst's ability to build trust and credibility among policy participants depends on social and interpersonal skills as well as technical abilities. With that in mind, I understand 1997 was a really good year for Napa Valley Cabernets.