♦ CHAPTER 2.
ECOSYSTEM-BASED MANAGEMENT

THE ADVANTAGES OF ECOSYSTEM-BASED MANAGEMENT

Natural resource management is often guided by the need to recover and protect populations of endangered and threatened species. Efforts to combat population declines of endangered and threatened species often focus on specific factors in a species' environment believed to affect birth or death rates. While this species-based approach has often prevented the extinction of a species, it has also resulted in piecemeal attempts that usually fail to recover and stabilize populations of threatened and endangered species. Additionally, this species-based approach fails to address the needs of unlisted species experiencing population declines that might necessitate their future listing.

Ecosystems are more than just a collection of species; they are complex, living systems influenced by innumerable climatic, physical, chemical, and biological factors, both within and outside of the ecosystem. A new paradigm in natural resource management has emerged that acknowledges this complex interplay of forces that shape and animate ecosystems. Ecosystem-based management is an integrated-systems approach that attempts to protect and recover multiple species by restoring or mimicking the natural physical processes that create and maintain diverse and healthy habitats

By incorporating an ecosystem-based approach, the ERP and the Strategic Plan signal a fundamental shift in the way the ecological resources of the Bay-Delta system will be managed.

By adopting an ecosystem-based approach, CALFED is not relinquishing its responsibility to recover endangered and threatened species, nor is it abandoning all species-based management efforts. Ecosystem-based management encompasses species management by enhancing and sustaining the fundamental ecological structures and processes that contribute to the well-being of a species. The ERP aims to recover threatened and endangered species not only by restoring habitats, but also by restoring the ecological processes that help create and sustain those habitats.

CONTRASTING ECOSYSTEM-BASED AND SPECIES-BASED MANAGEMENT

The difference between process-based restoration and conventional species-based management can be illustrated by the contrast between using hatcheries and ecosystem-based approaches to restore salmon. Hatcheries were initially constructed to compensate for habitat lost behind dams, but they are now used to compensate for a broad range of impacts on salmon production, including habitat degradation. This conventional, engineering-oriented, species-based approach yields an increase in fish populations, at least in the short term; however, hatcheries are vulnerable to disease and impose a variety of selection pressures that

Advantages of an Ecosystem-Based Approach over the Traditional Species-Based Approach

- Restoration of physical processes reproduces subtle elements of ecosystem structure and function in addition to the more obvious elements, thereby possibly enhancing the quality of restored habitat.
- Restoration of physical processes can benefit not only threatened and endangered species, but also unlisted species, thereby reducing the likelihood of future listings.
- Restoration of physical processes reduces the need for ongoing human intervention to sustain remnant or restored habitats.
- Restoration of physical processes may produce a more resilient ecosystem capable of withstanding future disturbances.

may make the fish less successful in the wild. Hatchery-produced fish compete with, and interbreed with wild fish, thereby affecting the gene pool and possibly reducing the fitness and overall vigor of local populations.

By contrast, a process-based ecosystem management approach seeks to restore the dynamic processes of flow, sediment transport, channel erosion and deposition, and ecological succession that create and maintain the natural channel and bank conditions favorable to salmon. If the processes that create the habitat for salmon can be restored, ecosystem restoration can be truly sustainable and can result in a system that benefits a range of other species as well, thereby avoiding future need for further listings of endangered species.

ELEMENTS OF ECOSYSTEM-BASED MANAGEMENT

In its monograph on the scientific basis of ecosystem management, the Ecological Society of America (1995) identified eight elements of ecosystem-based management that illustrate the character of this emerging paradigm:

1. **LONG-TERM SUSTAINABILITY IS A FUNDAMENTAL VALUE.** This element highlights the importance of intergenerational equity, suggesting that resources should be managed today to ensure that the needs of future generations will not be compromised (World Commission on Environment and Development 1987). In ecological terms, this is coming to be defined as passing on to future generations a set of natural capital resources equivalent to that which the present generation has available (Costanza and Daly 1992). The ERP addresses this element in by emphasizing the recovery of native species, by preserving biodiversity, and by emphasizing the restoration of ecological processes that allow ecosystems to be more self-sustaining.

2. **DECISIONS MUST BE BASED ON CLEARLY DEFINED GOALS AND OBJECTIVES.** This element highlights the need to be clear about what we want to achieve through management. Goals and objectives are to be stated in terms of desired future states, behaviors, or trajectories for ecosystem structure and function. Objectives are also to be stated in terms that can be measured and monitored. In this way, ecosystem management is not tied to an undefinable or unattainable pristine condition; instead, it provides considerable latitude for negotiating and defining desirable future conditions. Furthermore, because goals are to be stated in terms of measurable criteria, progress can be explicitly evaluated. The ERP and the Strategic Plan include both general goals and more specific measurable objectives.

3. **DECISIONS MUST BE BASED ON SOUND ECOLOGICAL MODELS AND UNDERSTANDING.** This element highlights the importance of rational, science-based models to decision making in ecosystem-based management. However, because humans are integral to the ecosystem to be managed, it also highlights the importance of models that integrate social, economic, and environmental components of the larger system. Conceptual models as heuristics and as a foundation for modeling expected outcomes in adaptive management are part of the Strategic Plan.

4. **COMPLEXITY AND CONNECTEDNESS ARE FUNDAMENTAL CHARACTERISTICS OF HEALTHY ECOSYSTEMS.** Evidence from management failures of the past suggests that there is considerable risk in attempting to manage individual resources independently of one another. By focusing attention on connectedness, ecosystem management reduces the risk of such failures. Restoration of Delta and estuarine ecosystems inevitably involves a concern with connectedness because of the importance of fluvial and tidal dynamics to their functioning. Recognition of the importance of interconnected habitats is also paramount when anadromous salmonids are one subject for restoration. The nested hierarchy of ecosystem management units in the ERP focus area is a further acknowledgment of the interconnectedness among elements of structure and function in the ERP focus area.

5. **ECOSYSTEMS ARE DYNAMIC.** Ecosystems are complex, self-organizing systems. With complexity comes uncertainty and imprecision in prediction. Ecosystem-based management cannot eliminate surprises or uncertainty. Rather, it acknowledges that unlikely and even unimagined events may happen. The management process must be designed to cope with such events. The Strategic Plan describes an adaptive management process that helps to account for the uncertainty inherent in restoring and managing an ecosystem. The program also recognizes the importance of dynamic processes in its concern over effects of the seasonal hydrograph on particular species and in its plan to recreate meander corridors along river courses. Other dynamic elements may have to be built into the restoration program over time, however, and adaptive experimentation can help to define the necessary degree of dynamic change to maintain ecosystem function.

6. **CONTEXT AND SCALE ARE IMPORTANT.** Each aspect of ecosystem structure and function has its own time and space scale. Spatial and temporal domains of management planning and implementation need to be congruent with those of critical ecological processes in the system to be managed. Management activities tend to be tied to social and economic schedules, not ecological schedules. Staged implementation, monitoring, and assessment schedules and adaptive experimentation all provide tools for strengthening the spatial and temporal patterning of restoration.

7. **HUMANS ARE INTEGRAL COMPONENTS OF ALL ECOSYSTEMS.** Humans are the single greatest modifier of ecosystem structure and function. Humans will also suffer the most serious consequences of changes that make ecosystems less able to sustain human life. Therefore, management of human activities must be an integral component of plans to manage ecosystems. This element may seem rather obvious but serves to emphasize the importance of linking the ERP with activities related to water quality, water supply reliability, and levee integrity. This element also reminds us that ecosystem management is a human problem, not an ecological one.

8. **ECOSYSTEM MANAGEMENT MUST BE ADAPTABLE AND ACCOUNTABLE.** Our understanding of ecosystems is incomplete and subject to change, so management planning and programs must be sufficiently flexible to respond to new information. Adaptive management provides this flexibility, and it employs the problem-solving power of the scientific method to maximize the information value of restoration actions so that we can improve our knowledge of the ecosystem as we restore it, thus improving the process of management over time.

Elements of Ecosystem-Based Management

1. Long-term sustainability is a fundamental value.
2. Decisions must be based on clearly defined goals and objectives.
3. Decisions must be based on sound ecological models and understanding.
4. Complexity and connectedness are fundamental characteristics of healthy ecosystems.
5. Ecosystems are dynamic.
6. Context and scale are important.
7. Humans are integral components of all ecosystems.
8. Ecosystem management must be adaptable and accountable.

ADDRESSING THE UNCERTAINTY INHERENT IN NATURAL SYSTEMS THROUGH ADAPTIVE MANAGEMENT

Through decades of scientific research, we have come to understand much about the Bay-Delta ecosystem and the species that depend on it; however, we do not understand all of the ecological processes and interactions that animate the ecosystem. Additional research can greatly improve our understanding, but it will never erase all of the uncertainty that is inherent in restoring and managing such a large, diverse, complex, and variable natural system. Ecosystem processes, habitats, and species are continually modified by changing environmental conditions and human activities; consequently, it is impossible to predict exactly how the Bay-Delta will respond to implementation of the ERP and other CALFED components. Restoring and managing the Bay-Delta ecosystem requires an approach that acknowledges the uncertainty in both the dynamics of complex systems and the effects of management interventions.

Holling (1998) classifies the practice of ecology according to two cultures, a dichotomy that can also describe the management of ecological systems. The first, traditional culture, is analytical and based on formally testing hypotheses to assess single causative relationships and attempting to find the single correct answer to questions and the single correct approach to solving problems. The second culture is integrative and exploratory, based on a comparative analysis of multiple hypotheses and an acknowledgment of uncertainty in management. Previous management of the Bay-Delta system has proceeded according to the first set of cultural practices. That is, historically, we have disregarded most of this complexity in resource management and treated such problems as though they were well defined in time and space and amenable to analysis (understanding) and remediation by standard methods. As failures in resource management based on this approach have become more visible and more serious, resource managers have shown increasing interest in methods that explicitly recognize the uncertainty inherent in management actions (Holling 1998). A suite of techniques collectively termed "adaptive environmental assessment and management," or simply "adaptive management," (Holling 1978, Walters 1986) has been adopted by several state and federal resource agencies as a practical approach to management under uncertainty.

According to Walters (1986), designing an adaptive management strategy involves four basic issues:

1. bounding the management problem in terms of objectives, practical constraints on action, and the breadth of factors to be considered in designing and implementing management policy and programs;
2. representing the existing understanding of the system(s) to be managed in terms of explicit models of dynamic behavior that clearly articulate both assumptions and predictions so that errors or inconsistencies can be detected and used as a basis for learning about the system;
3. representing uncertainty and how it propagates through time and space in relation to a range of potential management actions that reflect alternative hypotheses about the system and its dynamics; and
4. designing and implementing balanced management policies and programs that provide for continuing resource production while simultaneously probing for better understanding and untested opportunity.

Put another way, adaptive management involves: 1) having clear goals and objectives for management that take into account constraints and opportunities inherent in the system to be managed; 2) using models to explore the consequences of a range of management policy and program options in relation to contrasting hypotheses about system behavior and uncertainty; and 3) selecting and implementing policies and programs that sustain or improve the production of desired ecosystem services while, at the same time, generating new kinds of information about ecosystem function.

REDUCING UNCERTAINTY BY LEARNING FROM RESTORATION AND MANAGEMENT ACTIONS

Restoring and managing the Bay-Delta ecosystem requires a flexible management framework that can generate, incorporate, and respond to new information and changing Bay-Delta conditions. Adaptive management provides such flexibility and opportunities for enhancing our understanding of the ecosystem. Within an adaptive management framework, natural systems are managed in such a way as to ensure their recovery and improvement while simultaneously increasing our understanding of how they function. In this manner, future management actions can be revised or refined in light of the lessons learned from previous restoration and management actions.

The key to successful adaptive management is learning from all restoration and management actions. Learning allows resource managers and the public to evaluate and update the problems, objectives, and models used to direct restoration actions. Subsequent restoration actions can then be revised or redesigned to be more effective or instructive. In an adaptive management process, learning must be continuous so that ecological restoration continuously evolves as the ecosystem responds to management actions and to unforeseen events, and as management actions are revised in light of new information. Without effective learning, ineffective management programs are likely to be perpetuated, unanticipated successes will go unrecognized, and resources will not be efficiently allocated.

To facilitate learning, adaptive management emphasizes the use of the scientific method to maximize the information value of restoration and management actions. Resource managers explicitly state hypotheses about ecosystem structure and function based upon the best available information, and then they design restoration actions to test these hypotheses. In this respect, adaptive management treats all management interventions as experiments. This does not suggest that management interventions are conducted on a trial-and-error basis, because management actions are guided by the best understanding of the ecosystem at the time of implementation.

Adaptive management is analogous to the "clinical trial" in medicine. In a clinical trial, a new therapy is tested on many patients, the trial is carefully monitored, and the progress of the trial is evaluated at regular intervals to determine whether to continue with the trial, abandon the trial, or declare the new therapy a success. Clinical trials are not initiated unless there is a reasonable expectation of success. Similarly, CALFED will not initiate large-scale ecological restoration unless there is a reasonable expectation of success.

By treating interventions as experiments, resource managers ensure that management is as efficient and successful as possible in achieving its objectives—unsuccessful interventions will not be perpetuated or expanded and successful interventions can be modified to use resources efficiently (e.g., land, water, tax dollars). Designing management interventions as experiments can have significant benefits when it comes to evaluating success or failure, increasing understanding of system dynamics, and making better decisions in the future (Walters et al. 1988 and 1989, Walters and Holling 1990). In adaptive management, treating interventions as experiments involves:

- making management decisions based on the best available analyses and modeling of the system;
- being clear about what management intervention is expected to achieve in terms of restoring ecological structure and function and the implications for species conservation;
- designing management intervention to help distinguish among alternative hypotheses about ecosystem behavior, where practical and compatible with the long-term goals of the program; and
- monitoring the effects of management intervention and communicating the results widely so that progress relative to expectations can be evaluated, adjustments made, and learning achieved.

As in clinical trials, an adaptive management program should incorporate Bayesian statistical techniques to judge progress and update probabilities among competing hypotheses. These techniques differ from the traditional hypothesis-testing approaches that play such a dominant role in ecological practice. Bayesian techniques are used to determine the probability that a hypothesis is true given the available information; when more than one hypothesis is proposed, probabilities can be compared among hypotheses. Decision rules can therefore be built into the program that are more socially and ecologically relevant than the 0.05 significance criterion commonly used in ecology. This approach is more in keeping with the notion of the second alternative culture of ecology (Holling 1998).

MODES OF ADAPTIVE MANAGEMENT

Walters (1986) recognized three approaches to management:

- **TRIAL-AND-ERROR**, in which early management options are chosen at random and later choices are made from a subset of the early options that performed best;
- **PASSIVE ADAPTIVE**, in which a best management option is chosen on the basis of the current beliefs about system dynamics and this option is fine-tuned in relation to experience; and
- **ACTIVE ADAPTIVE**, in which two or more alternative hypotheses about system dynamics are explored through management actions.

TRIAL-AND-ERROR MANAGEMENT. The first approach is illustrated by early attempts at stream habitat rehabilitation in which alterations were made to streams, and those that proved successful (e.g., stayed in the stream, attracted fish) became favored interventions. Some element of trial-and-error is a part of virtually every management policy.

PASSIVE ADAPTIVE MANAGEMENT. Passive adaptive management is perhaps the most common form of management intervention these days. It is highly defensible in that the best management action is chosen based on the best available scientific information (although which information is best may be subject to debate). It fits well with the incremental remedial approach to policy evolution that is common to public agencies (Lindblom 1959). It is administratively simple because all "units" are treated alike, and information needs and information management are relatively simple. Learning about the system using this approach, however, is confined to a very narrow window, and there is practically no possibility of determining whether the underlying hypothesis about the system is right or wrong; therefore, although passive adaptive management takes uncertainty into account, it has only limited capacity to reduce uncertainty.

Many elements of the ERP may have to be implemented as passive adaptive projects. Passive adaptive management may be dictated because the value of knowing that option A is a better description of system dynamics than option B is less than the cost of obtaining the information, or the alternative action poses too great a threat to public safety or valuable infrastructure, or for a variety of other reasons. Despite its limitations as a tool for learning about the system, a properly designed passive adaptive experiment can provide important insights into workable, if not optimal, solutions.

Unfortunately, strict adherence to experimental protocols is impossible in such a large-scale, passive adaptive program such as the ERP. There is, after all, only one Bay-Delta system, and its various component parts are all strongly interconnected. Independent replication of control and treatment measures is impossible in either space or time, violating an important principle of experimental design. The degree to which cause and effect can be determined should be tempered by this unavoidable limitation. All manipulations within the ERP should be based on careful and creative design to enhance the opportunity for learning and an analytical program that will allow as much distinction between confounded effects as possible.

ACTIVE ADAPTIVE MANAGEMENT. Active adaptive management is the most powerful approach for learning about the system under management but also is often the most contentious. Active adaptive management programs can create the false impression that managers or scientists are going to toy with the resources on which other people's livelihoods depend. Nevertheless, there is an important role for active adaptive management in the ERP, notwithstanding the critical status of many of the species the ERP is intended to benefit. It is important to realize that the purpose of active adaptive management is not to push the system to its limits and see how it responds. Rather, the purpose is to use management as a tool to generate information about the system when the long-term value of the information clearly outweighs the short-term costs of obtaining it.

It may be useful to distinguish between two kinds of active adaptive management. For many situations, it may be clear what kind of intervention is needed (e.g., increased spring and summer flows into the Delta for salmonid conservation), but the magnitude of the intervention is uncertain. The concern is not with the form of the model relating flow to conservation, but with the parameters of the model. An active adaptive management experiment could be designed to improve the estimation of parameters by manipulating spring and summer flow in appropriate ways. For purposes of this discussion, this kind of adaptive experiment will be referred to as "adaptive probing". In some instances, adaptive probing can be designed around natural fluctuations in environmental variables. A good example is the experiment conducted to improve estimates of optimal sockeye salmon escapement to the Fraser River. The principal issue was the level of escapement that would maximize yield to the fishery. The benefit-cost ratio of the experiment to test the benefits of higher escapements was very high, but involved fishers foregoing catch to achieve higher escapements in the short term. The experiment was initiated in the 1980s with very positive results in terms of yields in the late 1980s and early 1990s. Another example of adaptive probing is the Vernalis Adaptive Management Program (VAMP) which is designed to improve the scientific basis for the protection of San Joaquin fall-run chinook salmon smolts during their migration through the Delta. The program is based on a conceptual design which is to test the hypotheses related to smolt survival from five sets of San Joaquin inflow and Delta export levels.

In other instances, the greatest uncertainty may be about the best kind of intervention. For example, which would be the management action for spring-run chinook: increased spawning escapement or reduced cross-channel transport? In this case, the concern is with the form of the model (although obviously the size of the intervention is also important). Again, an adaptive probing experiment could be designed to determine which model (escapement or Delta transport) was the more important in chinook conservation. For purposes of this discussion, experiments designed to distinguish among fundamentally different models (hypotheses) will be referred to as "adaptive exploration." The Bay-Delta ecosystem is replete with such unresolved alternatives. To the extent feasible, the ERP will capitalize on opportunities to distinguish among such alternatives through active adaptive experimentation. Tools for assigning probabilities to models and updating probabilities in the light of new information, as well as rules for efficient design of adaptive experiments, are provided in Walters (1986) and Hilborn and Mangel (1996).

EXPERIMENTAL PROTOCOL FOR ADAPTIVE MANAGEMENT

For all experiments, whether passive or active, the general protocol should be as follows:

1. **MODEL THE SYSTEM IN TERMS OF CURRENT UNDERSTANDING AND SPECULATION ABOUT SYSTEM DYNAMICS** and use the model to explore issues, such as the magnitude of effects that will derive from particular manipulations, how uncertainty affects outcomes, efficiency of various experimental designs, and the value of information about alternative dynamics. Models of the system may suggest that the most efficient approach is large-scale intervention, pilot or demonstration projects, targeted research, or some combination of these.

2. **DESIGN THE MANAGEMENT INTERVENTION TO MAXIMIZE BENEFITS IN TERMS OF BOTH CONSERVATION AND INFORMATION.** Where the modeling of management options suggests that more research is needed before any intervention should be attempted, other management measures may be necessary in the short term to ensure that endangered species do not suffer further declines.

3. **IMPLEMENT MANAGEMENT AND MONITOR SYSTEM RESPONSE.** In the case of large-scale manipulations, this must go beyond merely monitoring the response variables of interest

(e.g., fish abundance) to provide a report at the end on whether they changed in the desired direction. Monitoring, modeling, and analysis, perhaps together with targeted research, must be designed specifically to determine the extent to which the manipulation affected the variable of interest.

4. **UPDATE PROBABILITIES OF ALTERNATIVE HYPOTHESES** based on analytical results and, if necessary, adjust management policy.

5. **DESIGN NEW INTERVENTIONS BASED ON IMPROVED UNDERSTANDING.**

The experimental protocols for adaptive management are described in further detail in Chapter 3.

ADDRESSING POLITICAL, REGULATORY AND ECONOMIC UNCERTAINTY

The large scope of the ERP requires that it be implemented in stages over the course of several decades. Staged implementation facilitates an adaptive management approach by allowing resource managers to evaluate actions implemented early so that future restoration will benefit from the knowledge gained. It also allows restoration costs to be spread over several years.

Owing to the long implementation timeframe for the ERP, the ecosystem-based, adaptive management process must account for uncertainty produced by non-biological factors in addition to the ecological uncertainty inherent in restoring complex ecosystems. During the projected implementation period for the CALFED Program, there will be approximately eight presidential and gubernatorial elections. These state and national elections will inevitably affect the way existing public policies and programs are interpreted and implemented. Changes in administrations could lead to new state or federal laws, regulations, and programs relating to the regulation and management of water resources, endangered/threatened species, habitat, and ecosystem protection. Current debates concerning the need for new species listings, legal challenges to federal policies (such as Habitat Conservation Plans [HCPs], the "No Surprise" Rule and "Safe Harbor" provisions), and legal challenges to California's Natural Community Conservation Planning Act (NCCPA) process, reflect the potential for changes in law, regulation, and policy that could affect implementation of the ERP and the overall CALFED Program.

Similarly, the volatile nature of global economics has the potential to affect federal, state, and regional budgets and incomes. Fluctuations in the business cycle could ripple into the implementation of the ERP by affecting the funding available for ecosystem restoration or the demands placed upon Bay-Delta resources. The flexibility of an adaptive management approach can allow resource managers to respond to such external forces in much the same way that they respond to new information or unforeseen environmental events.

ONE BLUEPRINT FOR ECOSYSTEM RESTORATION

A single blueprint for ecosystem restoration and species recovery in the Bay-Delta System is a key ingredient for a successful and effective restoration program. Such a blueprint can be the vehicle for ensuring coordination and integration; not only within the CALFED Program, but between all resource management, conservation, and regulatory actions affecting the Bay-Delta System.

A single blueprint represents a unified and cooperative approach defined by three primary elements:

1. integrated, shared science and a set of transparent ecological conceptual models which provide a common basis of understanding about how the ecosystem works;

2. a shared vision for a restored ecosystem ; and

3. a management framework that defines how management and regulatory authorities affecting the Delta will interact and how management and regulatory decisions (including planning, prioritization, and

implementation) will be coordinated and integrated over time.

The integrated science and ecological conceptual models provide a common basis of understanding about how the ecosystem works. These elements, which include competing hypotheses and models, represent the foundation for transparent decision making based upon sound science. This is not to imply that these models are fixed, as they will be tested and modified over time in response to new information in accordance with the principles of adaptive management as part of the CALFED Science Program. Rather, the models represent a basis for guiding management and regulatory decisions at a given point in time. They also provide the rationales for these decisions.

The shared vision of ecological restoration serves to define the desired outcome. While each of the management and regulatory programs have their own distinct set of goals, establishing a unified approach requires that in meeting these goals the various programs also contribute to meeting common goals with respect to ecosystem restoration. The goals for ecological restoration and species conservation established in the ERP and MSCS provide a broad set of goals that provide the common vision for the single blueprint concept.

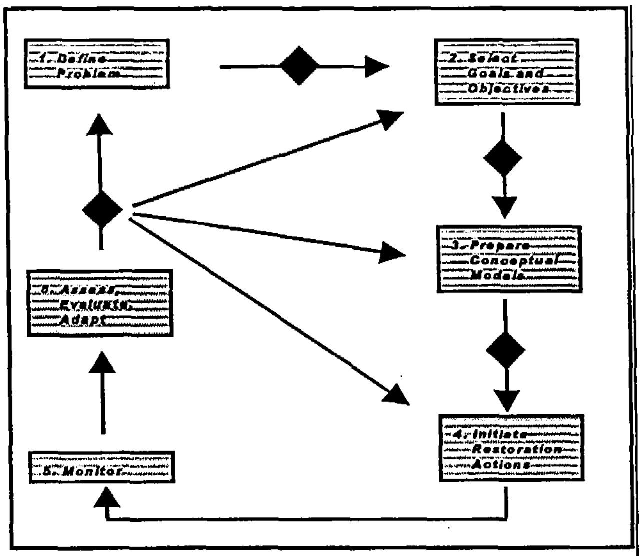
The management framework defines how parties will interact and how management and regulatory decisions will be coordinated and integrated over time. The management framework is designed to foster coordinated and consistent decision making over time. This management framework must be flexible, incorporating and responding to new information and changing Bay-Delta conditions. The framework must be designed to promote coordinated planning, prioritization, and implementation. It must also incorporate provisions for resolving management and regulatory conflicts that may arise.

BENEFITS OF A SINGLE BLUEPRINT

The benefits of a single blueprint approach include the following:

- improved understanding, both of the consequences of certain actions and why specific actions are undertaken;
- increased probability of achieving the desired level of ecosystem health for the Bay-Delta system;
- cost effectiveness;
- avoiding and/or reducing the potential for conflicts that could be counterproductive;
- providing greater management and regulatory certainty; and
- increased support for the program and program funding.

◆ CHAPTER 3. THE ADAPTIVE MANAGEMENT PROCESS



This chapter describes a stepwise procedure that will help incorporate adaptive management in the restoration and management of the Bay-Delta ecosystem. The succeeding discussion describes the steps involved in an adaptive management process, and Figure 3-1 illustrates the process.

DEFINING THE PROBLEM

The first step of an adaptive management process requires clearly defining a problem or set of problems affecting ecosystem health. Defining a problem usually requires determining the geographic bounds of the problem; the ecological processes, habitats, species, or interactions affected by the problem; and the time that the problem affects the ecosystem. Volumes I and II of the ERPP define problems that affect the health of the Bay-Delta ecosystem.

DEFINING GOALS AND OBJECTIVES

Once a problem has been bounded, it is necessary to articulate clear restoration goals and tangible, measurable objectives to provide direction to restoration efforts and to measure progress. Objectives must be tangible and measurable so that progress toward achieving them can be clearly assessed. For example, the following objective statement is too vague: "Improve the quality of habitat for winter-run chinook salmon." By contrast, a more specific statement is: "Restore flows and accessibility of Battle Creek to winter-run chinook salmon spawning within 7 years." Although objectives may sometimes be stated broadly, they must ultimately be made specific through models and hypotheses that translate the objectives into restoration actions.

The Strategic Plan defines broad goals and objectives for the Bay-Delta ecosystem in Chapter 4. Volume II of the ERPP defines targets and programmatic actions for the ecological management zones and units that comprise the larger Bay-Delta ecosystem.

DEVELOPING CONCEPTUAL MODELS

Many resource managers, scientists, and stakeholders interested in the restoration and management of the Bay-Delta ecosystem have implicit beliefs about how the ecosystem functions, how it has been altered or degraded, and how various actions might improve conditions in the system. That is, they have simplified mental illustrations about the most critical cause-and-effect pathways. Conceptual modeling is the process of articulating these implicit models to make them explicit.

Conceptual models can provide several benefits. The knowledge and hypotheses about ecosystem structure and function summarized in conceptual models can lead directly to potential restoration actions. They can highlight key uncertainties where research or adaptive probing might be necessary. Alternative, competing conceptual models can illustrate areas of uncertainty, paving the way for suitably-scaled experimental manipulations designed to both restore the system (according to more widely accepted models) and explore it (to test the models). Conceptual models can also help to define monitoring needs, and they

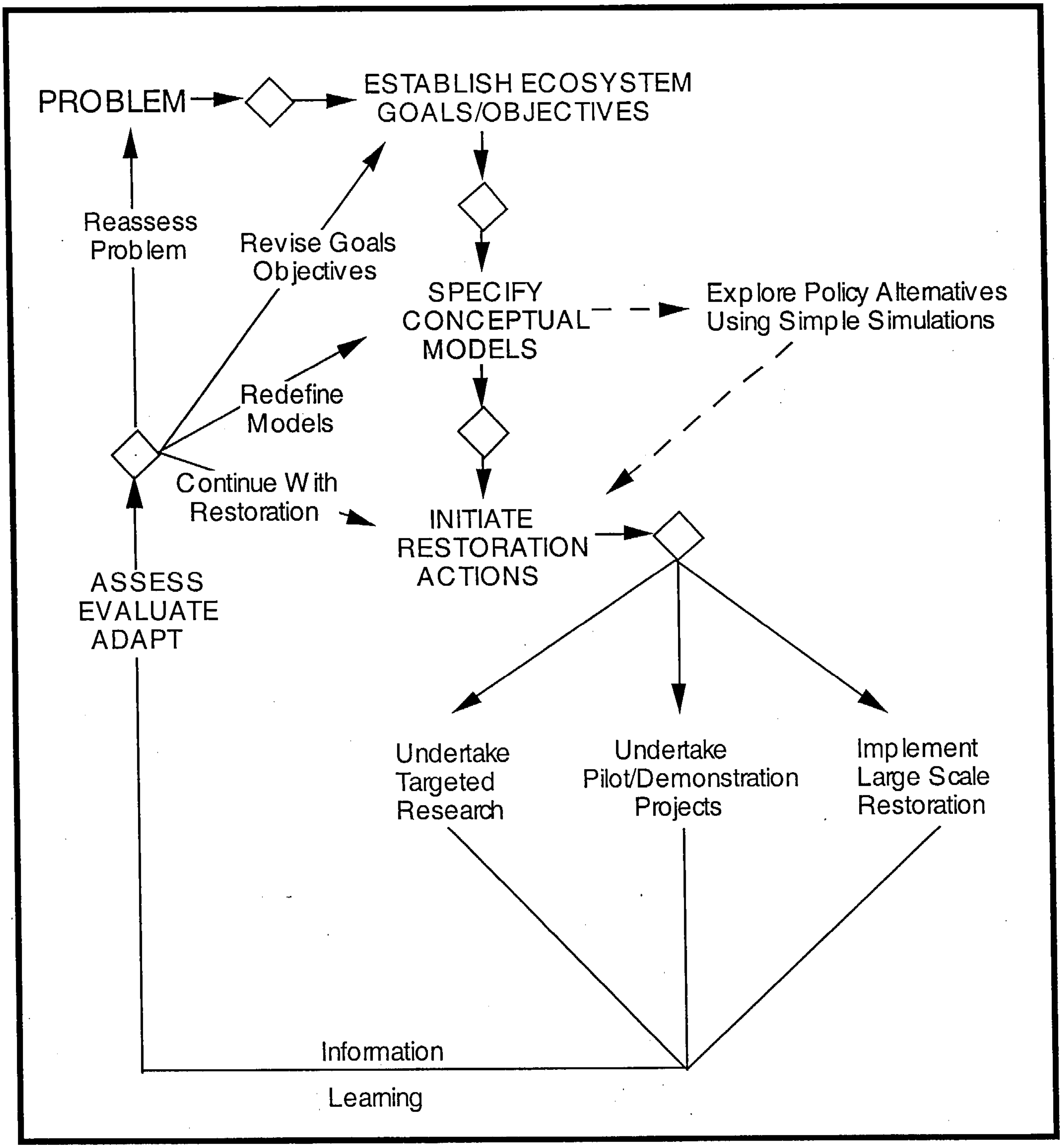


Figure 3-1: Diagram of the Adaptive Management Process.

can also provide a basis for quantitative modeling. Articulating conceptual models can also facilitate dispute resolution since differences between implicit conceptual models often underlie disagreements about appropriate restoration actions.

Conceptual models often suggest many possible restoration actions. In evaluating alternative actions, it is usually very helpful to conduct exploratory simulation modeling based on the conceptual models (Figure 3-1). These simulations are not intended to capture the complexity and richness of ecological processes, but to capture the essential elements of ecological structure and function that underlie management decision making. They are greatly simplified, clear caricatures of the system, just as the conceptual models are clear caricatures. Their purpose is to allow explicit exploration of the main pathways of causal interaction and feedback processes in the conceptual models and provide preliminary predictions of the consequences of different management actions. The simple simulations can aid the decision-making process in many ways. For example, simulation modeling can:

- identify logical inconsistencies in the conceptual models,
- clarify where the nodes of greatest uncertainty are in the conceptual models and where new information would be most useful to decision making,
- allow comparison of the benefits and costs of alternative models of the system and alternative management actions,
- provide a basis for determining how much of a particular kind of restoration action will be required to achieve measurable benefits within a specified period of time,
- provide a basis for determining the value to the ecosystem of new information that might be obtained through adaptive experimentation, and
- help communicate to a broader audience the current understanding of the problem and the explicit rationale for particular restoration measures or targeted research.

Developing Conceptual Models

Conceptual modeling: the process of articulating implicit models (simplified mental illustrations about the most critical cause-and-effect pathways) to make them explicit

- summarize knowledge and hypotheses about ecosystem structure and function
- highlight key uncertainties where research or adaptive probing might be necessary

Exploratory Simulation Modeling: to allow explicit exploration of the main pathways of causal interaction and feedback processes in the conceptual models

- greatly simplified, clear caricatures of the system
- provide preliminary predictions of the consequences of different management actions

Quantitative Modeling: to refine conceptual models or simulation models themselves when a more detailed evaluation of potential alternatives is required

Quantitative modeling may also be a helpful tool to refine conceptual models or simulation models themselves when a more detailed evaluation of potential alternatives is required (Figure 3-1).

Conceptual models are based on concepts that can and should change as monitoring, research, and adaptive probing provide new knowledge about the ecosystem. When key concepts change, the conceptual models should be updated to reflect those changes, thereby paving the way toward changes in management. This will not happen by itself but must be accomplished through a systematic, periodic (e.g., every 3 years) reevaluation of the conceptual models.

AN EXAMPLE OF CONCEPTUAL MODELS

There is no recipe for developing conceptual models; nor is there a template for what they should look like. There is no unique set of conceptual models that provides a basis for ecosystem restoration and that can be determined deductively. Conceptual models should be designed for a particular purpose and should contain only those elements relevant to solving a particular problem, including alternative explanations that might yield alternative solutions. The models presented below and in Appendix B are, therefore, simply illustrations of such models and their uses

This section provides an explicit example of a conceptual model (the effects of freshwater flow on fish and invertebrates in the upper estuary) to illustrate the ways such models can be used. Several additional examples of conceptual models are described in Appendix B. The models presented here and in the appendix cover the hierarchy of spatial scales important to ecological restoration, from the landscape scale to the scale of specific ecological processes.

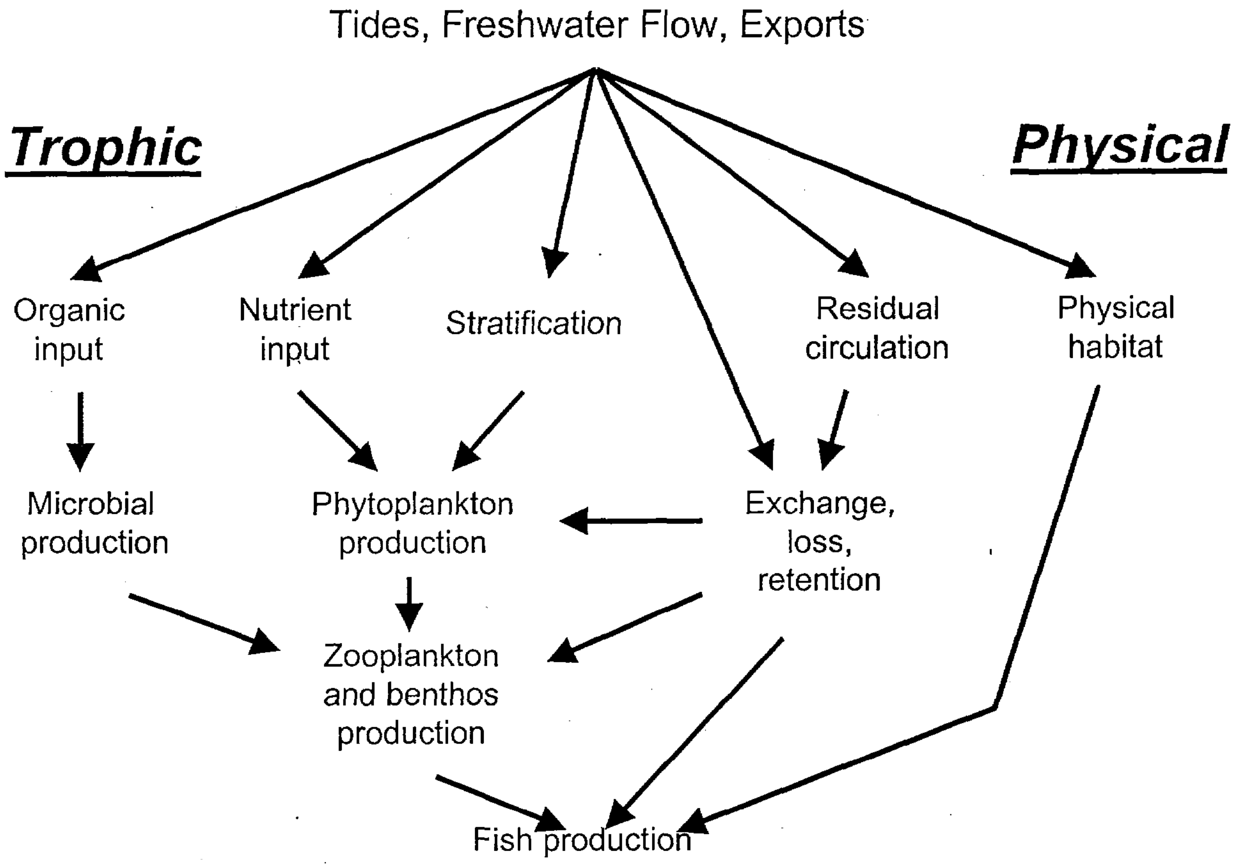
In the "Fish-X2" relationships (Jassby et al. 1995), abundance or survival of several estuarine and anadromous species is related to X2, the distance up the axis of the estuary at which daily average near-bottom salinity is 2 practical salinity units (psu). Because X2 is controlled by freshwater outflow from the Delta, it varies with both inflow and export flows. However, the relationship is entirely empirical and provides no indication of the mechanism controlling abundance or survival. The principal issue addressed here is how different concepts of the mechanism underlying the Fish-X2 relationship define different management tools for maintaining or enhancing populations of estuarine species.

Figure 3-2 illustrates the diverse mechanisms that could account for the X2 relationship for different species. The principal causative variables are freshwater flow and exports, both controllable at least to some extent, and tides, which are not under human control. Briefly, the relationships could arise (as similar ones do in estuaries in other parts of the world) as a result of stimulation of growth at the bottom of the food chain, which then propagates upward, eventually to fish. On the other hand, evidence from this estuary suggests that two kinds of direct physical effects on fish are the more likely mechanisms (Kimmerer 1998). First, flow conditions in the estuary set up by tides and freshwater input, and in some cases by export flows, may alter the retention of some species in the estuary, thereby affecting population size. Second, the amount of physical habitat may change with freshwater flow through such effects as inundation of floodplains or expansion of low-salinity shallow water habitat.

Now consider how potential management interventions are affected by these three scenarios. If the mechanism is stimulation at the base of the food chain, appropriate management actions include addition of nutrients or organic matter to the estuary. If retention is the issue, flows could be manipulated to lengthen or shorten the period of retention in the estuary. If habitat is the issue, physical restoration of habitat or judicious use of flow to increase the amount of habitat at critical times might be in order.

Thus, a very simple model illustrates how critically the management options depend on the assumed cause-and-effect mechanism as well as how various kinds of management interventions can be suggested by a conceptual model. To provide further detail, we use part of the Estuarine Ecology Team's report on the Fish-X2 relationships (Estuarine Ecology Team 1997). That report included a matrix (Figure 3-3) that summarized knowledge about each of the potential mechanisms underlying the Fish-X2 relationships. For each mechanism and each species, the importance of the mechanism is denoted by the size of the symbol. In addition, open symbols denote mechanism for which there is some scientific information, and closed symbols denote mechanisms about which virtually nothing is known.

Each of the mechanisms has a precise definition (Estuarine Ecology Team 1997), but we consider only a few of them here. First, examine the row labeled "Reduced Entrainment (CVP-SWP)." In addition to a number of smaller symbols, large open symbols are given for all the anadromous species except for splittail. Thus, the Estuarine Ecology Team believed that for these species, entrainment could explain at least part of the observed Fish-X2 relationships. Now examine the row labeled "Gravitational Circulation Strength." There are six large filled circles, including those for species that recruit from the ocean as well as several for those that move down-estuary during development and then reside primarily in Suisun or San Pablo Bay and the Delta. In this case, the



Note: The labels “trophic” and “physical” indicate that causative pathways on the left side of the diagram are more biological, based on feeding relationships, whereas those on the right side describe mechanisms that arise through interactions with physical conditions and abundances of species of interest. Tides, freshwater flow, and exports influence organic and nutrient inputs, stratification and gravitational circulation, and the extent of physical habitat with various characteristics. Organic and nutrient input can stimulate growth at the bottom of the food web, which may progress to higher trophic levels, such as fish. Export flow, together with residual and tidal circulation in the estuary, may interact with behavior to affect losses from the estuary or, alternatively, retention. Thus, fish may benefit from increased flow through increased food supply, improved retention in their habitat, or an increase in the quantity or availability of physical habitat.

Figure 3-2: Schematic Diagram Showing Potential Causative Pathways Underlying the "Fish-X2" Relationships

Species

X_2 Mechanisms	CF	PH	SF	WS	AS	SB	LF	DS	ST	CS	NM
Spawning habitat space		◯		○	◯	◯	●	⬤	◯	◯	
Spawning habitat access				○	○	○			◯	◯	
Cooccurrence of food		⬤		●	●	⬤	⬤	⬤	⬤	●	●
Rearing habitat space	◯	⬤	⬤	⬤	⬤	◯	◯	⬤	⬤	●	●
Predation avoidance: turbidity		●			●	○	●	●	●	○	⬤
Predation avoidance: shallow	●	●	●						●	○	
Predation avoidance: encounter	●						●	⬤	●	●	
Reduced entrainment (CVP-SWP)			●	○	◯	◯	◯	◯	●	◯	○
Reduced entrainment (PG&E)	●		●		○	○	⬤	⬤	●	○	●
Reduced entrainment (agricultural)			●		●	◯	●	⬤	●	●	●
Toxic dilution	●	●	●	●	●	○	●	●	⬤	●	●
Transport	●			◯	◯	◯	◯	●	●		
Gravitational circulation strength	⬤	○	⬤			⬤	⬤	⬤			⬤
Entrapment zone residence time						⬤	⬤	⬤			⬤
Temperature (as affected by flow)					●	●				◯	●
Strong migratory cues	●	●	●	◯	◯	●			●	◯	
Higher production of food	●	●			⬤	⬤	⬤	⬤	●		⬤

Relative Uncertainty

● Higher

○ Lower

Importance

⬤ High

● Low

◯ Upstream effect

Note: Symbols indicate a potential mechanism according to the key at right. Several minor mechanisms have been eliminated to simplify the diagram. "Upstream" effects refer to flow effects that occur entirely upstream of the Delta. The species abbreviations are defined as follows:

CF = bay shrimp, *Crangon franciscorum*
PH = Pacific herring
SF = starry flounder
WS = white sturgeon
AS = American shad

SB = striped bass
LF = longfin smelt
DS = delta smelt
ST = splittail

CS = Chinook salmon (note: few major effects are in the Delta)
NM = *Neomysis* and other mysids

Figure 3-3: Estuarine Ecology Team's Summary of Potential Causes Underlying "Fish-X2" Relationships team believed gravitational circulation to be an important mechanism although there was virtually no specific information on its effects. Similarly, "Rearing Habitat Space" was considered an important probable mechanism for the largest number of species although knowledge of this topic is limited. In these latter two examples, the Estuarine Ecology Team was exercising professional judgment in the absence of hard scientific information. Similar kinds of judgments will have to be made in decisions about ecological restoration. However, by employing adaptive management, we will be able to design restoration and management actions that allow us to learn about the mechanisms governing ecological function and species abundance while restoration is proceeding.

DEFINING RESTORATION ACTIONS

Conceptual models help to shape the character of restoration actions by identifying key uncertainties or by revealing the level of confidence that a particular action will achieve a given objective. Three types of management actions can be selected for implementation (Figure 3-1). **TARGETED RESEARCH** may be necessary to resolve critical issues about ecosystem structure and function that preclude us from even defining problems adequately. **PILOT OR DEMONSTRATION PROJECTS** can help to determine the practicality or effectiveness of restoration actions, allowing resource managers to evaluate alternative actions or build confidence in the ability of a particular action to achieve an objective. For those restoration actions about which we are reasonably confident will achieve an objective, we can begin **FULL-SCALE IMPLEMENTATION.**

These three types of actions are not mutually exclusive, and all might be used to address a particular problem. Furthermore, they are a set of options and not necessarily progressive.

MONITORING RESTORATION ACTIONS

It is critical to monitor the implementation of restoration actions to gauge how the ecosystem responds to management interventions. Monitoring provides the data necessary for tracking ecosystem health, for evaluating progress toward restoration goals and objectives, and for evaluating and updating problems, goals and objectives, conceptual models, and restoration actions. Monitoring requires measuring the abundance distribution, change or status of ecological indicators.

Ecological indicators are measures of ecological attributes, populations, or processes that can be measured. Indicators include:

- response variables, such as abundance of important species, used to assess trends and measure progress;
- input variables that can be manipulated directly, such as salinity and temperature;
- summaries of habitat characteristics, such as dimensions of river meanders or area of tidal marsh habitat, that indicate progress toward a goal;
- other variables, such as birth, survival, or migration rates, that can be used to interpret the other data and assess the effects of particular manipulations; and
- intermediate variables that may help to understand the trajectory of response variables and some of which might eventually serve to indicate ecosystem condition (e.g., primary or secondary production, inputs or turnover rate of organic carbon or nutrients, or aspects of foodweb structure).

Ecological indicators should based on goals and objectives, and on important elements of conceptual models. Indicators will need to be reevaluated as the system develops and as models change.

EVALUATING AND REVISING PROBLEMS, CONCEPTUAL MODELS, AND RESTORATION GOALS, OBJECTIVES, TARGETS AND ACTIONS

As we learn more about the ecosystem, it is important that this new information feed back into the planning and management process. Problems, conceptual models, goals, objectives, quantified targets, and the restoration actions that flow from them must be re-evaluated and, if needed, revised to reflect the most current information. Such re-evaluation and revision is essential to ensure that the restoration program is achieving its objectives efficiently and to prevent wasting resources upon restoration actions that do not contribute toward achieving objectives.

To better define restoration objectives, the ERP should specify quantitative restoration targets, as best as possible. The ERP has yet to complete this important task. A process for setting, evaluating, and revising restoration targets needs to be developed. This process should be science-based, using the best available scientific information and judgement through the CALFED Science Program and the independent scientific review process.

PROPOSED ERP TARGET SETTING, EVALUATION, AND REVISION PROCESS

The process proposed here would be used to evaluate and refine existing targets, set targets for program objectives and elements without quantitative targets, and future target evaluation and refinement through the adaptive management process.

STEP 1: Initial evaluation of existing ERP targets for strategic objectives and ecosystem elements.

- Step 1A: Proposed ERP Science Board, or an equivalent independent scientific review panel, evaluates existing quantified targets in the ERPP and classifies them into three categories: (1) stated target has sufficient scientific basis and stated justification or rationale is sufficient; (2) stated target has sufficient scientific basis but stated justification insufficient; (3) stated targets needing revision (i.e., insufficient scientific basis). Steps 1A and 1B conducted concurrently.
- Step 1B: Staff (CALFED or combined CALFED/agency/stakeholder staff) identify strategic objectives and ecosystem elements without quantified targets. Steps 1A and 1B conducted concurrently.
- Step 1C: Science Board develops priority list of strategic objectives and ecosystem elements for target setting (i.e., those without targets), target revision, and additional target justification (based on information from Steps 1A and 1B). Identifying objectives and elements for which there is currently insufficient scientific information to establish targets, and the required information needs (and perhaps actions to provide needed information), would be included in this step.

STEP 2: Provide additional scientific justification for targets with sufficient scientific basis.

For targets determined by the Science Board to be scientifically sound (i.e., sufficient scientific basis) but lacking sufficient justification, staff (CALFED or combined CALFED/agency/stakeholder staff) and/or consultants would write scientific justification. Step 2 would be performed concurrent with Step 3.

STEP 3: Establish and revise targets by topic area.

For objectives and elements without existing quantitative targets or with existing targets needing revision, small technical teams would establish or revise targets and provide justifications for sets of objectives and elements by topic area (e.g., fish species, fluvial geomorphic processes, Delta wetland and aquatic habitats). Technical team composition: A team for each topic area or category composed of three to five environmental scientists and managers with expertise in the that topic. The Science Board, in consultation with ERP, agency, and stakeholder staff, would establish topic areas and select team members. The Science Board would provide scientific guidance and oversight for the teams. Staff would provide team administrative support and day-to-day management. For each objective/ element topic area, the product of this step would be proposed targets based on best current scientific information (i.e., report presenting proposed targets and scientific justification). For targets that can not be determined because sufficient scientific information is currently lacking, identify scientific information needs and related actions (research, modeling, monitoring). Step 3 would be performed concurrent with Step 2.

STEP 4: Scientific review of proposed targets.

Step 3 products (proposed targets and scientific justifications) would be reviewed by the Science Board and made available for review and comment by agency and stakeholder environmental scientists and managers. These reviews could be sequential with revisions after the Science Board and before broader review, or concurrent with revisions after all comments.

STEP 5: Policy level review and establishment of targets.

- Step 5A: Ecosystem Roundtable review, comment, and recommendations on proposed scientifically based targets. Recommendations should include policy justification.
- Step 5B: CALFED Management Team and Policy Group (or future CALFED/ERP governing entity) consideration of proposed scientifically based targets and Ecosystem Roundtable recommendations. Final policy review, revision, and establishment of targets.

DECISION NODES

Adaptive management includes several crucial decision nodes (Figure 3-1) that have the potential to be bottlenecks. Decisions about which projects to implement and which to postpone, when to gather more information and when to proceed with large-scale restoration, when to terminate projects and when to change direction, and when to declare the success or failure of a particular intervention are difficult and contentious. Although rigorous data analysis and modeling can help with these decisions, they cannot determine the decisions. Efficient progress in adaptive ecological restoration will depend on having institutional arrangements that facilitate effective communication and decision making. A significant element of subjectivity in decisions about whether to proceed will always exist. Open discussion may help to resolve many contentious issues and decisions; nevertheless, in such a large, complex public program there will always be a need for a formal dispute resolution process.

The bottleneck in decision nodes is also important for regulatory compliance. Many of the decision points in the adaptive management system will require state and federal agency approvals for actions recommended by the adaptive management process. Early identification of the decision points requiring public agency approvals can reduce the potential for delays resulting from a disconnect between the adaptive management process and applicable regulatory requirements. Adaptive management decisions made within a regulatory context also will be less vulnerable to challenges.