The Adaptive Management Approach in the Strategic Plan: Building Adaptive Management Into the Program

The problem of restoring ecosystem quality in the Bay/Delta area is challenging to say the least. First, the problem is not that well defined. What does "restoring ecosystem quality" mean in the practical sense and how will we know if we have achieved it? Who decides what constitutes acceptable ecosystem quality? What kinds of intervention and how much intervention will restore ecosystem quality? We have attempted to address this uncertainty by specifying clear goals and objectives, but this is only one important step toward defining the problem.

Second, whatever the real problem is, it is manifest at various time and space scales. Human intervention at any "scale" will propagate inward and outward to have consequences at all scales. It is not at all clear at what scale it is most advantageous to intervene to achieve any particular objective. Nor are the most advantageous kinds of interventions well known and tested.

Third, any intervention will be costly in resources spent and/or opportunities foregone. Without some effective and objective means of prejudging interventions and evaluating the consequences of those that are implemented, scarce resources may be wasted in ineffectual management actions.

These characteristics, a diffuse problem that is manifest in various ways and for which remedial actions are highly uncertain, are typical of issues in natural resources management. Historically, in resource management we have disregarded most of this complexity and treated such problems as though they were well defined in time and space and amenable to analysis (understanding) and remediation by standardized 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. A suite of techniques, collectively termed Adaptive Environmental Assessment and Management or simply Adaptive Management (AM)(Holling 1978, Walters 1986) is gaining popularity as a practical approach to management under uncertainty. Although by no means universally accepted, AM has been employed in the design of large scale environmental restoration projects (Lee 1993). Since the need for CALFED is largely a consequence of the application of the traditional form of analysis and remediation in resource management, it seems doubtful if more of the same will suffice to restore the ecosystem. AM is the most promising available alternative approach.

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 our existing understanding of the system(s) to be managed in terms of explicit models of dynamic behavior that spell out both assumptions and predictions clearly enough 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, AM involves: 1) having clear goals and objectives for management that take account of 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.

The critical variable in AM is uncertainty, uncertainty in the dynamics of complex systems and uncertainty in the consequences of various potential management interventions. In a program like CALFED, the uncertainty is compounded by the need to effect change at large time and space scales. The only way to learn about such systems and their dynamics is through large scale experiments. CALFED is such an experiment and it is impractical, indeed impossible to gather the information necessary to predict the consequences of CALFED without undertaking CALFED. The program to solve the problem, therefore, becomes the experiment to learn about the problem. The trick in AM is to design the management program so that beneficial actions are taken in a timely manner but that projects are structured so that alternative concepts are probed and learning is an active consequence of management. As Lee (1993) argued, information has value both as a stimulus for action and as a product of action. The information value of action is the component of value routinely ignored in traditional approaches to management (Healey and Hennessey 1994).

If we are to realize the information value of management actions they must be designed as experiments and evaluated as experiments. Unfortunately, strict adherence to experimental protocols is not possible in a restoration project like CALFED. There is, after all, only one Sacramento/San Joaquin delta and its various component parts are all strongly interconnected. Independent replication of control and treatment measures is not possible in either space or time. Nevertheless, designing management interventions as experiments still has 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, 1989, Walters and Holling 1990).

Walters (1986) recognized three approaches to management: 1) trial and error in which early management options are chosen at random whereas later choices are made from a subset of the early options that performed best; 2) passive adaptive in which a "best" management option is chosen on the basis of the current paradigm about system dynamics and this option is fine tuned in relation to experience; and 3) active adaptive in which two or more alternative hypotheses about system dynamics are explored through management actions. The first approach is illustrated by early approaches to stream habitat rehabilitation in which supposedly beneficial alterations were made to streams and those that proved successful (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 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. It fits well with the incremental remedial approach to policy evolution that is common to public agencies (Lindblom 1959). It is administratively simple since all "units" are treated alike and information needs and information management is relatively simple. In passive adaptive management, however, learning about the system is confined to a very narrow window and there is virtually no possibility of determining whether the underlying hypothesis about the system is right or wrong. Passive adaptive management will be an important component of the CALFED adaptive management strategy. The notion of CALFED itself, complex as it is, can only be implemented in a passive adaptive way. There is no alternative "policy" to CALFED that can be implemented as a contrasting experiment. As well, many elements of CALFED may have to be implemented as passive adaptive projects either 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, because stakeholders won't buy into the experiment, 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.

Active adaptive management is the most powerful approach for learning about the system under management but also often the most contentious. Active adaptive management is an admission that we don't understand fundamental aspects of system behavior as they affect things that are very important to us (endangered species, economic value, rare habitats, environmental quality, etc.). Active adaptive management programs tend to create the impression that managers or scientists are going to screw around with resources on which other people's livelihoods depend. Nevertheless, there is an important role for active adaptive management in CALFED, notwithstanding the critical status of many of the species CALFED is intended to benefit. To this end, 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. 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 two kinds of adaptive experimentation. For many situations, it may be clear what kind of intervention is needed (increased spring and summer flows into the delta for salmonid conservation for example) but there is uncertainty about how much intervention is needed. The concern is not with the form of the model relating flow to conservation but with the parameters of the model. An active adaptive experiment could be designed to improve the estimation of parameters by manipulating spring and summer flow in appropriate ways. For our purposes, let's call this kind of adaptive experiment "adaptive probing". A good example of this kind of experiment was undertaken to improve estimates of optimal sockeye salmon escapement to the Fraser River. In the 1970's, historic data were consistent with the hypothesis that escapement over the past decade was near that for MSY. However, an alternative hypothesis that 2X the present escapement would provide much greater sustained yields could not be ruled out. 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 1980's with very positive results in terms of yields in the late 1980's and early 1990's.

In other instances, the greatest uncertainty may be about the best kind of intervention (increased spawning escapement or reduced cross channel transport as conservation measures for spring run chinook, for example). In this case, for illustration, the concern is with the form of the model (although obviously the size of the intervention is also important). Again, an active adaptive experiment could be designed to determine which model (escapement or delta transport) was the more important in chinook conservation. For our purposes, let's call experiments designed to distinguish among fundamentally different models (hypotheses) "adaptive exploration". The Bay/Delta ecosystem problem is replete with such unresolved alternatives. Where opportunities exist to distinguish among such alternatives through active adaptive experimentation, CALFED should seriously explore the possibility. Tools for assigning probabilities to models, updating probabilities in the light of new information and rules for efficient design of adaptive experiments are provided in Walters (1986) and Hilborn and Mangel (1996).

CALFED is not a single project but many projects that must be interlinked into a coherent whole. The size and complexity of CALFED introduces additional dimensions into the problem of adaptive design. Since it is quite possible that the success of some projects may depend on the outcomes of others and that some interventions may be synergistic whereas others are antagonistic, the sequencing of projects and their arrangement in space and time are all potentially important to the success of CALFED. A hierarchical set of rules for deciding among projects needs to be developed to guide decision making. These rules might be incorporated into formal models of decision making but my experience has been that both agencies and members of the public are somewhat antagonistic to such formalization. As a preliminary list, the decision rules might look something like the following:

1. Emphasize projects that will have the greatest absolute benefits and the greatest benefit:cost ratio for native species.
2. Emphasize projects that will provide the most useful information about system dynamics.
3. Emphasize projects that will provide results in a short time frame.
4. Emphasize projects that will be the most self-sustaining in the long term.
5. Emphasize projects that are complementary in their effects unless the conflict provides important information about system dynamics.
6. Emphasize projects that have high public support and visibility.

Given the nature of CALFED, it is likely that many, perhaps even most projects will not, individually, have measurable consequences for the species of concern. It may be helpful in CALFED to classify projects into three types: 1) Small projects that individually will have small impacts on the system or species recovery but which, collectively may have important overall impacts or serve complementary functions (e.g. small scale riparian restoration, screening of irrigation intakes); 2) large scale projects that individually should have measurable impact on the system or target species and can be implemented as passive adaptive experiments; and 3) adaptive probing or adaptive exploration projects designed to distinguish among competing hypotheses.

For smaller projects the criteria of success may have to be more modest than species recovery. Suitable criteria for small projects might be that the desired habitat attributes (ecological structure and function) were created, the desired habitat attributes were maintained over time with limited human intervention and species of concern made use of the habitat in the ways hypothesized. At this level of evaluation it should be possible to build some important learning opportunities into management with little overall risk to any sensitive species. For example, experiments designed to test competing hypotheses about the most efficient and effective kinds of habitat design could be done at this scale with the proviso that there is an important limitation on interpretation; population level effects cannot be inferred from local responses (Riley and Fausch 1995).

Large projects provide the opportunity for evaluating overall population responses as well as creation and maintenance of structural and functional aspects of habitat. Because of the diversity of activities contemplated under CALFED and its relatively short time horizon, incorporating efficient experimental design of even large projects may be difficult as confounding among the effects of different projects is likely. Opening up of the floodplain, changing hydrographs, removing dams to provide access to significant amounts of habitat would all constitute large scale projects with potential dramatic effects. However, collections of smaller projects might constitute a significant intervention with measurable population level effects. Whether or not large scale projects should be staged to ensure that their independent effects can be distinguished is not obvious. Such decisions could be assisted by modeling outcomes based on expected value of perfect information (e.g. Walters 1986).

As noted earlier, adaptive probing or adaptive exploration experiments are likely to be contentious. In some instances, however, they may be the only way to determine the practical benefits of certain kinds of management interventions. For example, if it is hypothesized that increasing spring and summer flows through the delta will benefit anadromous salmon an adaptive probing experiment seems to be the only feasible way to determine how large a flow will be required to achieve a particular benefit. Since any manipulation or reallocation of water is likely to be costly, experiments with flow may have a very high information value. As noted earlier, smaller scale experiments may be relatively easy to implement and can provide significant learning opportunities.

Experimental opportunities at the landscape level

The scientific review team recommended that every opportunity be taken to experiment at the landscape scale. If we define the landscape as the CALFED solution area, then CALFED is a landscape scale experiment. However, it can only be pursued as a passive adaptive experiment. Within the CALFED design there will be many levels of manipulation so that defining expected outcomes at each stage will be an important part of the passive adaptive experiment.

Experimental opportunities at the ecosystem level

The collection of ecosystems within the bay/delta and the solution area that will be subject to manipulation as part of CALFED is reasonably large. Most of the large scale interventions anticipated under CALFED are manipulations at the ecosystem level (e.g. removal or set back of levees, changes in hydrology, reduction in toxic or nutrient inputs, etc.). There will be opportunities for both passive and active adaptive experimentation at the ecosystem level. The problem will be to ensure experimental designs that are not so confounded as to be uninterpretable.

Experimental opportunities at the habitat level

Habitat manipulations are likely to be among the most numerous activities under CALFED. Individually they may not have large impacts on critical aquatic species but may be significant for less wide ranging species (amphibians, reptiles, insects, plants, etc.). These kinds of small scale manipulations provide many obvious opportunities for experimentation and active learning. They may also provide the easiest ways to get communities and interest groups directly involved with CALFED activities.

Experimental opportunities at the species level

Species level projects might include both attempts to reduce adverse impacts of certain introduced species (harvesting of *Potamocorbula*, for example) and attempts to increase abundance and/or distribution of desirable native species (through introductions or short term culture to get local populations above critical levels, for example). The information value of such management actions can also be considerable if they are designed as proper experiments.

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

1. Model the system in terms of the hypotheses about system dynamics and use the model to explore issues such as the magnitude of effects that will derive from particular manipulations, how uncertainty effects outcomes, efficiency of various experimental designs, the value of information about alternative dynamics, etc.
2. Design the management intervention to maximize benefits in terms of both conservation and information

3. Implement management and monitor key variables.
4. Update probabilities of alternative hypotheses based on monitoring results and, if necessary, adjust management policy.
5. Design new interventions based on improved understanding.

At the heart of adaptive management is the intimate and hierarchical connection between hypotheses about system dynamics, critical variables that will permit evaluation of hypotheses, and monitoring. Although certain kinds of information will be generally useful and will form a part of monitoring and evaluation regardless of the management program, many kinds of information will be specific to particular hypotheses and experiments. As a consequence, there will be no universally applicable set of indicators or monitoring program. Both will be specific to the particular models and management interventions that come to form CALFED.

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