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Adaptive management in river restoration : theory vs. practice in western North America



**Author**
Levine, Jessie

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# Adaptive Management in River Restoration: Theory vs. Practice in Western North America

**Jessie Levine**
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## ABSTRACT

Adaptive management is a resource management approach that acknowledges our limited understanding of how natural systems respond to human alterations by treating policies and management interventions in natural systems as experiments from which to learn. In a relatively new field such as river restoration, adaptive management is especially appealing, as it allows managers to learn while acting and promises to reduce uncertainty. By interviewing practitioners and reviewing restoration and adaptive management plans, I assessed the application of adaptive management in ten river restoration projects on the west coast of North America. Although definitions and applications of adaptive management vary widely among practitioners, the projects considered here share three common elements: recognition of uncertainty in river restoration and management, a commitment to monitor, and willingness to adjust actions based on information learned about the system. Most interviewees noted that it is too early to single out any positive ecological or social outcomes or even specific knowledge gained about the system through adaptive management; moreover, the site specific conditions of each stream have largely precluded knowledge transfer between restoration efforts. Practitioners identified a considerable number of barriers in attempting to implement adaptive management. Social and institutional challenges include high costs and limited availability of funding, a mismatch between the lengthiness of the adaptive management process and short funding cycles, agency and stakeholder impatience with the slow pace of adaptive management, a lack of leadership for monitoring and coordinating efforts, and risk aversion among agency personnel and stakeholders. Technical challenges encountered include a limited understanding of how to apply adaptive management and difficulties in translating results from site-level restoration projects to an understanding of the river system. The case study analyses suggest that the successful application of adaptive management will require long-term and stable funding, a long-term institutional commitment, greater leadership, more structured coordination, and training for resource managers.

## INTRODUCTION

Adaptive management is a resource management approach that purports to solve a number of problems that have plagued traditional natural resource management. For example, despite mounting pressure for increased exploitation of resources, science has failed to improve our ability to predict how natural systems will respond to new management policies. Society has continued to invest in basic research about natural systems, with resource managers "cautiously regulated harvests" (Walters 1986), i.e. allowing resource extraction at conservative rates that are assumed to be less harmful. In essence, "science" and "management" have pursued their agendas independently and with minimal interaction, rather than informing and learning from each other. In addition, natural resource management is continually plagued by crises caused by our focus on short-term and local scales and single targets, piecemeal management policies, a lack of flexibility in institutional arrangements, and increasingly fragile ecosystems (Walters and Holling 1990, Holling 1995).

Adaptive management emerged as a response to these problems. Adaptive management, or "learning by doing," treats policy and management interventions in natural systems as experiments from which to learn (Lee 1993, Lee 1999). The adaptive management approach stems from the recognition that natural systems and the interactions between people and ecosystems are unpredictable (Gunderson et al 1995). Adaptive management recognizes the need for management actions to proceed even if our understanding of a system and the effects of management on a system is incomplete (Johnson 1999). Therefore, adaptive policies are designed to test hypotheses about system response to human interventions (Lee 1993). In short, "management actions are taken not only to manage, but also explicitly to learn about the processes governing the system" (Shea et al 1998).

Adaptive management is valuable in controversial situations because it provides a "framework for identifying resource issues and establishing values," making it particularly valuable in controversial situations (Wieringa and Morton 1996). Moreoever, adaptive management allows for management decisions to be re-examined and revised based on new information (Wieringa and Morton 1996). In theory, adaptive management should increase rates of learning and reduce uncertainty about natural systems. Adaptive management also promises to enhance the flow of information among stakeholders, creating a forum for "shared understanding" among the diverse groups concerned about the natural resource at hand (McLain and Lee 1996).

Various models of adaptive management have been proposed, ranging from simple to fairly elaborate (see Figure 1). Many researchers have emphasized the importance of stakeholder involvement throughout the process for improving the quality and perception of decisions made at each step (Dovers and Mobbs 1997, Shindler and Cheek 1999). An idealized cycle of adaptive management includes the following sequence of steps, which are continually repeated (adapted from Johnson 1999, Parma et al 1998, Walters 1997, and Healey et al 2004): (1) establish a stakeholder adaptive management team; (2) define the problem(s) to be addressed; (3) establish goals and objectives; (4) specify a conceptual model that expresses the collective understanding of how the system in question functions, highlighting key uncertainties and acknowledging factors that are outside of the system; (5) develop hypotheses about the effects of different management actions that address the uncertainties; (6) design management experiments/interventions to test hypotheses while meeting management goals; (7) design a monitoring plan to measure the impact(s) of management interventions; (8) implement management interventions; (9) monitor; (10) evaluate the impacts in terms of management goals and hypotheses; (11) reassess and adjust the problem statement, goals, conceptual model, interventions, and monitoring plan.

Despite the appeal of adaptive management, there is widespread agreement among researchers that significant obstacles have precluded its widespread adoption and limited its effectiveness as a management approach where attempted. A major barrier is the fundamental tension between the strategies of science and management (Lee 1993). In a fairly pessimistic assessment of adaptive management of riparian and coastal marine ecosystems, Walters (1997) attributed low success rates in implementing adaptive management to the following factors: (1) a focus on perfecting models rather than field testing them; (2) the expense and risk of undertaking large scale experiments; (3) fear among research and management organizations that adaptive management may undermine their credibility; and (4) fundamental conflicts among diverse stakeholders about ecological values. Other obstacles include the high costs of information gathering and monitoring, resistance from managers who fear increased transparency, political risk due to the uncertainty of future benefits, difficulty in acquiring stable funding, and fear of failure (Lee 1993). Through analysis of adaptive management in the Florida Everglades, Gunderson (1999) concluded that three major barriers are inflexibility in social systems, little resilience in ecological systems, and technical challenges associated with experiment design.

Adaptive management is the operative management strategy in a range of resource management settings, including fisheries, forestry, wetlands, agriculture, watershed management, and species conservation. Well-known North American examples of adaptive management include the Florida Everglades (Gunderson 1999), the Columbia River basin (Lee 1993), the Colorado River (Collier et al. 1996), the Chesapeake Bay (Hennessey 1994), the Mississippi River basin (National Research Council 2004), the Kissimmee River in Florida (Light and Blann 2000), forests and rivers throughout British Columbia (Taylor et al. 1997; Walters 1997; McLain and Lee 1996; Ward et al. 2003a; Ward et al. 2003b, and otheres) and boreal forests in Alberta, Canada (see http://www.ameteam.ca/index.html). Farther away, adaptive management is being used to manage water quality in Australia (Gilmour et al. 1999), grasslands in New Zealand (Allen et al. 2001), marine areas in Southeast Asia and the Pacific (see http://www.lmmanetwork.org/index.htm), coastal systems in East Africa (Torell 2000) and rivers in the Kruger National Park, South Africa (Rogers 1998). Many of these efforts are in the planning stages and have not yet begun to implement management experiments. Although the majority of these high profile examples are taking place at fairly large spatial scales and most of the adaptive management literature focuses on its value for ecosystem management, adaptive management has also been adopted at smaller scales. In river management, adaptive management is being applied at multiple spatial scales, ranging from specific projects on a reach to basin-level management.

In a relatively new field like river restoration, adaptive management appears particularly promising. Downs and Kondolf (2002) noted that "because river systems are not fully understood, no river restoration scheme can ever be fully guaranteed to succeed." This makes adaptive management valuable, since it provides a formal structure for learning. Moreover, "communicating the lessons of a project to others is critical" for increasing success in the future (Downs and Kondolf 2002). Kondolf and Micheli (1995) also highlighted the need for evaluation of restoration projects over at least a decade, and they recommended an adaptive management approach in which the method of evaluation ties into the specific goals of the project.

Given the continued interest in adaptive management and the institutional mandate to include adaptive management in many river restoration efforts, the skepticism in the literature about its success raises the question of how well adaptive management has worked in recent applications. The purpose of this study was to review and analyze the application of adaptive management in ten river restoration projects on the west coast of North America, by interviewing practitioners and reviewing restoration and adaptive management plans. Specifically, I sought to answer three questions:

(1) How is adaptive management being applied in river restoration?

(2) Why are practitioners using adaptive management?

(3) How well is adaptive management working?

## STUDY APPROACH

Case Study Selection: To gain a broad understanding of adaptive management in river restoration in western North America, I selected ten case studies of adaptive management efforts that include diverse restoration projects and methods at varying spatial scales. Most of the case studies that I considered are California-based, primarily because local practitioners were more amenable to participating. Table 1 summarizes the types of projects, locations, and watershed sizes. Projects are coded to preserve the anonymity of interviewees.

Review of Plans: To begin to answer the study's questions, for the case studies selected, I reviewed any documents detailing the project's adaptive management approach; these included existing adaptive management plans, adaptive management sections of restoration plans, progress reports, and journal articles or conference proceedings describing the project or program.

Interviews: For each case study, I interviewed one or two practitioners involved in the implementation of adaptive management (a total of fourteen interviews). I conducted thirteen of the interviews over the phone and one in person. My interviewees included scientists from local, state, and federal agencies, utilities, and water districts, private consulting firms, and NGOs. I did not strictly follow my list of interview questions (Appendix 1) because in some cases, time precluded a full interview, while in others I was able to find answers to the questions in supporting documents. The primary themes of the interviews are as follows:

- Definitions of adaptive management
- The types of restoration efforts being undertaken within the adaptive management framework
- The spatial scale of application of adaptive management
- Steps of the adaptive management approach being implemented
- Extent of stakeholder involvement and role of stakeholders
- Rationale for adopting adaptive management
- Ecological outcomes of adaptive management
- Social outcomes of adaptive management
- What has been learned about the system through adaptive management
- The extent of feedback from monitoring to management changes
- How knowledge has been shared across scales and projects
- Major challenges encountered in implementing adaptive management

## RESULTS

The case studies, types of restoration projects, project intents, interviewees, and organizational affiliations are summarized in Table 2. Three of the ten projects (C, G, and H) considered are in the planning stages, while the others listed are already underway.

### 1. How is Adaptive Management Being Applied in River Restoration?

#### Varying Definitions of Adaptive Management

A striking result of this research is the great variation in how practitioners define adaptive management. Definitions of adaptive management included: "acting with thoughtfulness and going back to see if your objectives are being met or if you made a mistake," "learning from our mistakes," "responsible mistake making," "recovery from damage," "trying things with the notion that if it doesn't work, you are prepared to go back and change it," an "excuse for failure…to cover us all," taking the time to "clearly define questions and hypotheses that are reasonable for…the projects that are being done," "every action having a testable hypothesis," and "thinking more upfront about design of the project and monitoring it so that you can answer specific questions."

#### Types of Restoration and Project Scales

Just as there are various definitions of "adaptive management," there are also multiple types of river restoration. Table 2 highlights the diversity of restoration project types that are using an adaptive management approach – including environmentally friendly flood control, experimental flow releases, and the addition of woody debris. Despite the diversity of restoration methods, most of these projects were undertaken to improve in-stream habitat for endangered or threatened species of salmonids. In the case studies reviewed, adaptive management is more often applied at a sub-river spatial scale, such as a site level or reach level.

Steps of the Adaptive Management Process: Goals, Conceptual Models, Monitoring, Feedback

Given the tremendous diversity in definitions of adaptive management, it is not surprising that these projects vary in their incorporation of different steps of the adaptive management process. While all of the efforts considered here have been undertaken to achieve specific outcomes, only about half have formally articulated their *goals and objectives*. Among these, goals differ widely in nature and scope. Some are qualitative, e.g. general descriptive goals about fish and habitat restoration, rather than numerical targets. Programs with more quantitative goals fall into two categories: those with numerical goals that are linked to *specific actions*, e.g. the installation of a certain number of habitat structures or the purchase of a certain quantity of water; and those with goals that are linked to *specific ecological endpoints*, e.g. numbers of juvenile fish. Practitioners noted that goals linked to actions rather than endpoints are easier to achieve, particularly because it is difficult to attribute large ecological changes to any single management action. In only three cases reviewed here was learning about the system an explicit goal of the adaptive management effort.

Arguably, all of the projects reviewed here involve *models* and *hypotheses*; what varies is the degree to which managers have formalized them. Only about half of the case studies have developed explicit conceptual models and hypotheses. In these case studies, the conceptual models are mostly qualitative descriptions of how the system works, and they tend to be quite elaborate and complex. (Figure 2 is an example of two of six conceptual models that have been developed for the Tuolumne River in California.) In cases where models and hypotheses have not been formalized, management actions are often undertaken based on an unstated hypothesis, i.e. a practitioner believes that a particular action is the one most likely to succeed, or a list of limiting factors. In these projects, a conceptual model appears to underlie actions taken even though it may not be formally articulated. One scientist went through the process of developing a conceptual model to come up with a number of treatments and a time frame for each, but then decided to simplify the model when he realized that the experiment was fairly intuitive and that other stakeholders were not interested in a complex model; in this case, modeling consisted of "putting numbers to our intuition."

The common element of all of the initiatives considered here is *monitoring*. However, monitoring programs vary greatly in structure, frequency, length, scope, and scale. For example, monitoring of Project J consists of a relatively informal annual "walk-through" to inspect a flood control project and assess sediment and vegetation conditions. Data was initially gathered by community members, but more recently a county public works agency took over the monitoring. In contrast, a more elaborate and structured monitoring program for

Project I includes surveys of adult and juvenile salmon, monitoring of other species at specific sites, and data collection on invertebrates and riparian vegetation. Public agencies, irrigation districts and scientist consultants are all involved in the monitoring. For site specific restoration projects on many rivers in California, monitoring is typically limited to one to three years, and monitoring efforts are often limited to a specific project site. In the case of flow experiments, monitoring is typically ongoing for the duration of the experiment. The monitoring planned for Project C will last for at least ten years and will include both site-specific and riverwide monitoring of variables including the amount of gravel moved, the rate of gravel movement, the amount of new spawning habitat created, the amount of fine sediment deposited on the floodplain, and changes in riparian vegetation. For Project G, data will be gathered for sixteen years in total.

The extent of *feedback from monitoring to management decisions* varies among the case studies reviewed and seems largely tied to the usefulness of the monitoring itself. In many cases, practitioners noted that limited monitoring (due to finite funding cycles or limited resources) has resulted in less-than-definitive information that can not be effectively integrated into management decisions. In other cases, practitioners have struggled to "scale up" results from project-specific monitoring on a particular reach to an understanding of the larger system. Other scientists noted that "confounding factors" (e.g. habitat restoration projects underway concurrently with experimental flow releases) have made it difficult to attribute changes to specific management actions. Moreover, since most adaptive management efforts are relatively young, there has not yet been ample time to gather enough data to adjust decisions. A notable exception is Project J, where monitoring resulted in the redesign and reconstruction of the original traditionally engineered flood control project. Scientists and managers working on Project I have noted that it has been difficult to understand how to translate the results of project-specific monitoring into river scale management changes.

Stakeholder Participation

Although stakeholder involvement is included in all of these case studies, the role of stakeholders varies by project. Stakeholder groups involved in the case studies include representatives of local, state, and federal agencies, government officials, farmers, landowners, Tribes, fishermen, environmental interests, citizen groups, watershed councils, and scientists. The rationale for stakeholder involvement and roles played by stakeholders is project-specific. In one case, the involvement of multiple stakeholder interests evolved from controversial projects, while in another, a public agency has done active and intentional outreach to involve as many different interests as possible.

Every manager with whom I spoke emphasized the importance of involving diverse interest groups. Nonetheless, interviewees recognized that increasing participation may result in a more complicated, lengthier planning process and that the planning process can be greatly simplified when few stakeholders exist. In most cases, non-agency stakeholder groups serve an advisory role to public agencies. Rarely have citizens been involved in developing conceptual models, deciding about management actions, or gathering and analyzing data.

## 2. Why Are Practitioners Using Adaptive Management in River Restoration?

The rationale for using adaptive management differs among practitioners and programs. Some practitioners commented that adaptive management is the *most sensible way* to approach a new field like river restoration, noting that adaptive management is quite simply the "right way to manage" the system. Others specifically chose adaptive management because they recognized unique conditions that would favor an experimental approach, e.g. plenty of water, stakeholder support, and long-term funding. Other scientists view adaptive management as *what they have always done*, namely being prepared to go back and change things that don't work; for these managers, there was no explicit shift to adaptive management. Lacking a full set of tools needed for flawless restoration work, other managers emphasized the importance of "plunging in" and doing the best they can, knowing that mistakes will be made and that these mistakes will contribute to the learning process. For them, the benefit of adaptive management is that it includes a process to figure out what the mistakes are (monitoring), and a feedback mechanism to address and correct them.

Still other interviewees reported implementing adaptive management *because it is required* by funding agencies. Several of these cases repositioned their work within the adaptive management model in order to secure funding. One scientist noted that adaptive management was adopted to *move controversial projects forward*, since it is an approach that stakeholders and other interests perceive as flexible and less binding. By using "adaptive management," potentially contentious projects have been able to proceed more quickly and smoothly.

## 3. How Well Is Adaptive Management Working?

### Ecological and Social Outcomes

Most managers reported that it is too early to identify any positive ecological outcomes from their adaptive management projects. In some cases, scientists have observed specific changes, e.g. increased fish populations, but noted that it may be difficult to accredit these changes to their management interventions because of the sheer number of factors that affect fish populations. In only one of the cases considered here, scientists directly attributed positive changes in the variable of interest (e.g. fish population size or amount of floodplain habitat) to the management interventions undertaken as part of adaptive management. In another case, scientists initially attributed positive changes in fish populations to their restoration efforts but later altered their conclusions when they realized that climatic effects outweighed the effects of the restoration actions.

Only a few practitioners spoke of social benefits. Project J, located on a small urban stream, is an important exception: as adaptive management evolved, a citizen group that had been convened to modify the original flood control project became an officially recognized watershed council that serves as an advisory body to public decision-makers. In short, through adaptive management, citizen stakeholders "went through a complete transformation" from "trouble-makers to critically needed stakeholders." Another interviewee noted that adaptive management has taught agency personnel the benefit and necessity of greater stakeholder involvement. However, one scientist noted that adaptive management has been somewhat divisive, since it has caused conflicts among stakeholders and differences of opinion about how and at what pace of action to proceed.

Learning and Knowledge Transfer

If adaptive management is "learning while doing," one measure of its effectiveness is what has been learned and how management has adapted to new information. Most of the practitioners interviewed commented about specific things that they had learned about the river system through adaptive management, although a few noted that it is too soon to tell. Project J is a prime example of learning through adaptive management: an initial failure in a flood control project taught stakeholders the importance of channel width-depth ratios and mature vegetation in designing an equilibrium channel for flood control; the project design and objectives were altered based on this new information.

Although many interviewees acknowledged the great potential of knowledge transfer among projects, they noted that information sharing has been largely limited to "casual" collaborations among scientists working on projects on multiple rivers. Science conferences and meetings focused around adaptive management have facilitated some information sharing among practitioners and scientists. On the other hand, one interviewee noted that efforts to share lessons learned with other scientists became competitive rather than collegial because a major funding institution sponsored the meeting and scientists no longer felt free to discuss problems. While conferences, meetings, and scientific papers may allow practitioners to share what they have learned, one scientist reported that limited time and a demanding schedule precludes attending conferences and keeping abreast of relevant scientific literature.

Many practitioners commented that the site-specific factors of each river and watershed – including species compositions and hydrologic regimes – may preclude the transferability of knowledge from one place to another. What may be more transferable than ecological understanding are lessons learned about the restoration process, such as how to set up monitoring programs, how to work with stakeholders, and how to control for confounding factors in experiment design.

Major Challenges

Practitioners have faced – and continue to face – many challenges in implementing adaptive management (Table 1). Many interviewees noted that the high cost, paired with *inadequate funding,* have been major hurdles to adaptive management. Adaptive management is not only *expensive* but also requires long-term funding for pre-project data collection and monitoring. However, many grants only provide *short-term funding*. For example, many grant making institutions offer grants of three years, which leaves only enough funding for a year each of design, construction, and monitoring. One year of monitoring is certainly not enough time to see meaningful results. Although a current proposal solicitation package is for three years of monitoring, managers recognize that biologically, three years is not even enough time to assess a system's response. In one case, limited funding has led to a monitoring approach in which managers attempt to do "everything" without doing any one thing particularly well. Planning processes may also be costly, particularly if they are lengthy and include multiple stakeholders. For local agencies attempting to carry out adaptive management, the funding mechanisms for restoration projects are generally only sufficient for construction and maintaining what has already been done, not for extensive monitoring or experimentation. Practitioners noted that insufficient financial resources have resulted in limited flexibility to try different management approaches, and inadequate time for scientists to share what they have learned and to learn from other scientists. Associated with inadequate funding are *limited staff resources* for all steps of the adaptive management process, particularly data collection and analysis. One interviewee noted that the major challenge he faces is that monitoring is "time consuming" and "pain staking." .

A *reliable source of funding* is also important, but rarely available. Funding institutions often shift their goals and objectives, making it difficult to continue projects whose projects are not compatible with the new priorities. One practitioner referred to adaptive management as the solution to the "problem du jour," noting that when an environmental problem or issue is no longer interesting, there may no longer be funding to continue with work that is already underway. Many adaptive management efforts are dependent upon grants attained through competitive processes, resulting in few assurances that funding will be available in the long-term.

Another challenge for many of the case studies is a *lack of leadership and coordination* of the overall adaptive management effort. This problem may be related to inadequate funding. Without some leadership, oversight, or coordination, knowledge gained in one location may fail to feed back into management practices in other locations. One scientist commented about the "exciting idea" of treating many watersheds as a single experiment, in which different hypotheses are tested in different places and results are aggregated and compared. Yet he noted that this can not happen without a single person responsible for managing and overseeing these experiments.

Many interviewees emphasized social challenges. Several commented that in river management, implementing adaptive management may require overcoming *risk-averse values* that have traditionally dominated the field of water resources management. In some cases, the adaptive management experiments themselves are difficult to implement because they are perceived as risky: for example, a project that involved intentional levee breaching made nearby landowners very nervous. In this case, managers had to limit their experimentation to certain areas where they could prove that they would do no harm. *Opportunity costs* may also be a barrier to successful adaptive management. One interviewee noted that in order to maintain experimental controls associated with a series of flow experiments, he needed to disallow potentially advantageous habitat restoration projects.

Other practitioners noted the challenge of getting managers and stakeholders “on board” with a *new approach* that is conceptually difficult to understand and represents a dramatic shift from traditional resource management. Even when managers understand adaptive management, the process can be thwarted if implementing agencies don’t have the scientific skills to carry out experiments. Managers may also fear failure: while traditional management approaches may be believed to “work,” adaptive management is politically risky because it involves experimentation. In another case, there has been *tension between a methodical scientific approach and a “common sense” approach*: for example, if something appears not to be working, the “common sense” approach would call for shifting courses immediately, while a scientific approach might require additional monitoring to more definitely prove that an intervention did not fulfill management goals.

For many of the cases reviewed here, a major challenge has been agency and stakeholder impatience with the lengthiness of the process. Several of the cases reviewed here are still in the planning phase, and experiments themselves can require many years before results are apparent. One interviewee observed that many non-scientist stakeholders and agencies who want to see results quickly believe that adaptive management is taking “too long.”. Another interviewee noted that some stakeholders and more “traditional” resource managers have grown frustrated by the length of time required for planning and monitoring (especially when it seems clear that an action isn’t “working”). Management interventions can also be stalled by lengthy bureaucratic processes: one scientist commented that institutional decision-making took so long that by the time an experimental flow was provided, it was too late to benefit fish populations.

A *lack of thorough and adequate documentation* has also impeded adaptive management. With overburdened resource managers, there is “no time to write it all down” and therefore a huge potential for important information to be lost. For example, those who are monitoring and analyzing data may not remember the original goals of a project or why it was designed in a certain way.

Technical challenges abound. The most general technical challenge is an inadequate understanding of how to apply adaptive management. For example, it has been difficult for scientists involved in Project H to *link the results of project-level adaptive management experiments to an understanding of the larger river system*. In cases where adaptive management is required by funding institutions, managers have faced an additional challenge of attempting to retrofit a pre-existing restoration program to fit a new model. One interviewee commented that scientists working on some of these projects have been “half-assing” adaptive management.

Other technical challenges relate to *monitoring* and *data interpretation*. Interviewees discussed the difficulty in choosing metrics that will adequately track variables of interest. Measurement is also a challenge; one scientist noted that at different flow levels, measurement methods may need to be changed, but that it is difficult to be comfortable with results obtained from different sampling techniques. Yet another issue is how to minimize or eliminate confounding effects, such as other restoration efforts underway.

## DISCUSSION

The Umbrella of Adaptive Management

This study has illuminated the great diversity that exists within so-called "adaptive management" projects, in terms of definitions provided by practitioners, types of projects implemented, spatial scales, steps of the process, and stakeholder participation. One important theme that emerges from the research is that there is no single method of adaptive management; that is, theory and practice are quite distinct. One interviewee was reluctant to use the phrase "adaptive management," noting that the term is so overused that it has come to mean very little. Another scientist commented that although adaptive management is "mapped out in a simplistic, mechanistic" manner, in reality it is a "messy iterative process" that can never be applied in the purist sense. It *is* important to note that despite the differences, all of the case studies consider here share three key elements: (1) acknowledgement of uncertainty in river restoration and management, (2) a commitment to monitor, and (3) willingness to adjust actions based on information learned about the system. On the other hand, it is unclear if *any* of the case studies considered here are testing the major uncertainties about the system; it appears that most of these projects are actually pursuing a course that they are confident will work and monitoring to verify the success. In short, the experimental nature of these projects is not readily apparent.

An Adaptive Management Spectrum

Those who adhere to a strict, purist definition of adaptive management might contend that some of the case studies reviewed are not actually practicing adaptive management. Rather than engage in debate about the proper definition of adaptive management, a more illustrative approach is to classify these case studies along a spectrum, from least complex to most complex ("pure" adaptive management). Researchers have identified three types of adaptive approaches that vary in complexity. In *trial and error learning*, early management decisions are "haphazard," while later decisions are "made from a subset that yields better results" (Walters and Holling 1990). A somewhat similar albeit more thorough approach is described by Johnson (1999) as "*monitor-and-modify*." In this approach, management interventions are determined based on conventional wisdom or the best available data, and the effects of the interventions are monitored. Data from monitoring serve to evaluate and modify the policy relative to management goals. (It is important to note that Johnson classified this approach as a "traditional," non-adaptive management approach): In *passive adaptive management*, managers determine the best possible model based on existing information and previous experience in similar systems, and management proceeds assuming that this model is correct. Monitoring data contributes to improvements and refinements of the model along the way, and managers choose the next actions based on this new information (Walters and Hilborn 1978). In *active* *adaptive management*, all management actions are "deliberate experiments." Managers implement different management actions to test a range of hypotheses about how a system works; monitoring provides information about the validity of each hypothesis (Walters and Hilborn 1978, Walters and Holling 1990). This spectrum of adaptive approaches serves as a useful framework for understanding the differences and similarities between the projects considered here.

Projects C, G, and H fit the "active adaptive management" definition. Most of the work planned as active adaptive management involves experimental flow regimes, an approach that seems well suited to testing multiple hypotheses. All of these projects will test hypotheses about flow levels over many years (much longer time scales than the trial and error/monitoring or passive approaches), monitor results, and use the results to choose among various management options. These case studies have had the most active and thorough stakeholder participation. All of the active adaptive cases have thoroughly and explicitly developed goals, conceptual models, and hypotheses.

Although active adaptive management is the "most powerful approach available to managers" (Healey et al., 2004), it is clearly a slow process. The case studies considered here that fit the definition of active adaptive management all involve much lengthier time scales – ranging from ten to twelve years of experimentation (in addition to several years of baseline data collection prior to experimentation) – than the passive adaptive management projects. Only one of the active adaptive management cases, Project G, has already moved from planning to experimentation. In this case, the modeling process was simplified because the interventions made "such intuitive sense" and the number of stakeholder interests was small (just four main stakeholder groups, including public agencies). In Project H, the planning is largely complete and the main challenge has been finding managers "capable" of implementing the plan. In Project C, the combination of a commitment to stakeholder-driven planning combined with a large number of diverse stakeholders has resulted in a very slow planning process; this program is still in the planning stages.

Associated with the lengthiness of active adaptive management is significant cost. For Project H, one scientist estimated that the annual cost of adaptive management is expected to be $12 million. For a much smaller river (Project G), an interviewee estimated that the adaptive management program would cost about $2.5 million a year on average. Although one scientist attributed much of the cost to foregone energy revenues (from the hydropower facility on the river), a scientist involved in project C estimated that monitoring would like account for about half of the total cost of doing active adaptive management.

Passive adaptive management is underway in Projects B, D, E, and I. One practitioner attributed the widespread use of passive rather than active adaptive management to fear of failure, noting that programs can not afford to do active experimentation when regulatory agencies expect or require a particular outcome. For all of these projects, existing knowledge about the system has led to a single "best" hypothesis about a management approach expected to be most successful.

Goals and objectives vary among the passive adaptive management cases studies – from specific and quantitative to rather general and qualitative. All of these projects involve conceptual models, hypotheses, and monitoring programs. In most of these cases, the goals and models apply to the entire river system and are not specifically related to the project. Most of these case studies are focused on specific reach-level habitat restoration projects with associated reach-scale monitoring of local effects. The monitoring programs are typically short-lived, and lessons learned may inform the design of other projects, but short-term funding cycles often preclude making further changes at the site based on lessons learned. However, learning from one site can affect the design of projects at other sites on the same river. All of the passive adaptive management case studies have river-wide monitoring of fish populations, but there are few links between river-wide monitoring and project-level experiments. For Project E, monitoring on a control stream provided additional information about the efficacy of the chosen management approach.

Of the projects considered in this study, Projects A, F, and J are examples of the "monitor-and-modify" or "trial and error" approaches. None of these examples have developed explicit conceptual models or hypotheses about system processes, but most have specific goals and objectives (a combination of qualitative and quantitative) associated with a management intervention or suite of interventions. All of these projects have monitoring efforts, but they differ in terms of structure and formality. In all of these cases, the results of monitoring have informed future management decisions. These are examples of ad-hoc adaptive management: in Projects A and J, observations from site-specific failures informed future management decisions and an adaptive approach evolved naturally without any explicit adaptive management plan. In the case of Project F, scientists developed a monitoring program to assess the effectiveness of a mandated management action, and the surprises encountered and lessons learned have fed back into management changes.

Meeting the Challenges: Conditions for Success

Given the challenges faced and the diversity of efforts considered here, we can identify several conditions required for successful implementation of adaptive management. On a logistical level, a *long-term, stable source of funding* is clearly imperative; this includes funding for all steps of the process: baseline data collection, planning, modeling, implementation, and long-term monitoring. Active adaptive management typically requires greater amounts of funding than passive adaptive management. Funds for monitoring have traditionally been inadequate to gather the breadth of data over a sufficient time scale to truly learn; one practitioner estimated that monitoring is likely to account for about half the costs of the project on which he is working. In only one case considered here was the institution overseeing adaptive management able to internalize the costs (through increases in customers' electricity rates). In all other cases, the issue of funding is central. The combination of changing funding priorities, political leadership, and funding through competitive grant programs translates into little assurance that long-term funding will be available for adaptive management. This may require reworking the details and rules governing funding cycles, moving from three-year to multi-year funding. The issue of inadequate funding is particularly crucial for passive and active adaptive management programs**.** Therefore, moving to a more complex, thorough adaptive management approach requires ever-greater funding.

*A long-term institutional commitment* to a new approach is essential for learning, feedback and ecological improvements. This will require the support of stakeholders, staff, and agency directors. Gaining the confidence of stakeholders appears to be especially important for smooth progress and functional working relationships. In cases where an initial effort has been made to bring stakeholders on board, adaptive management has proceeded more smoothly. Securing this commitment may be the most difficult challenge to overcome, since it requires a fundamental shift in thinking about resource management, willingness to try new approaches, institutional flexibility, and especially patience, since many years of data may be required to indicate whether something is "working." A fundamental tension in stakeholder-driven adaptive management is that increasing stakeholder participation tends to lengthen the process (requiring multiple iterations of each step), but with more stakeholders, there may be greater pressure for the pace to proceed more rapidly.

Adaptive management requires *leadership and more structured coordination* in order to promote learning, both within a single river system (where the results of one project should inform other projects) and across rivers. Lack of leadership is particularly significant in cases with multiple people working on different projects on a single river or in cases where multiple similar rivers are all testing different hypotheses. Without a distinct person responsible for oversight and coordination of adaptive management, knowledge gained in one location may fail to be integrated into projects and efforts at other locations. In short, this lack of coordination may translate into the loss of information gained at considerable cost. Another role for leaders and coordinators of adaptive management efforts is *training* for those expected to implement adaptive management: because adaptive management has multiple and often ambiguous definitions, resource managers may not understand what adaptive management is and how they can actually apply it.

### Adaptive Management and Water Conflict

Most of the case studies in this research are located in California, a place known for intense conflicts over water resources. Not surprisingly, the California cases are quite complex institutionally: multiple agencies govern water resources and provide funding, and there are many diverse stakeholders, including multiple agencies, farmers, environmental groups, scientists, academics, and landowners. It is important to consider how this context influences the application of adaptive management. Much of the adaptive management theory was developed by fisheries scientists in British Columbia, Canada, where there is less conflict around water, less demand relative to supply, and fewer stakeholder groups. It may be that a different model of adaptive management is needed in

California. The geographic bias of the sample size, combined with the small number of cases considered, suggests that research into other examples of adaptive management in river restoration is important for understanding the degree to which these findings can be generalized to other locations. Nonetheless, most of the technical and institutional constraints discussed here are likely to be present in many regions.

## CONCLUSIONS

This study has highlighted the muddled reality of adaptive management – its range of meanings, applications, scales, and uses. Most of the benefits – ecological improvements, social improvements, and learning – have yet to be realized. The multitude of technical and institutional challenges that are impeding adaptive management efforts remain to be addressed. The literature on adaptive management is full of articles delineating many of the same obstacles found here. Yet despite the hurdles, many practitioners in the field of river restoration recognize the tremendous appeal of this approach, and some even consider it to be a necessity. Although this research has included several cases of adaptive management that are driven by institutional requirements, in the majority of projects presented here, practitioners and scientists have *chosen* to use adaptive management – whether or not they labeled it as such – because they see it as the only way forward in a new field with great uncertainty.

The use of adaptive management requires a dramatic shift from traditional approaches of natural resource management. Yet in the past thirty years, there has been a major shift in how we view our rivers, and the field of restoration emerged to solve problems that had become apparent. Perhaps adaptive management will take hold in a similar way, providing the link between science and management that may be crucial for restoring our rivers to healthier conditions. In short, it is simply too early to tell if adaptive management can live up to its potential. Provided that patience and a commitment to sound science prevail over the desire to see instant results, with time we should begin to reap the benefits of adaptive management: an increased understanding of river dynamics, an expanded ability to implement successful river restoration projects, and an improvement in the relations among the diverse groups with a stake in our rivers.

## ACKNOWLEDGMENTS

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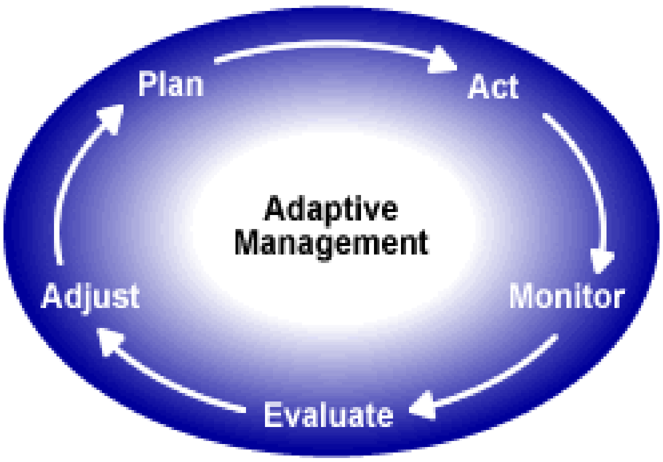
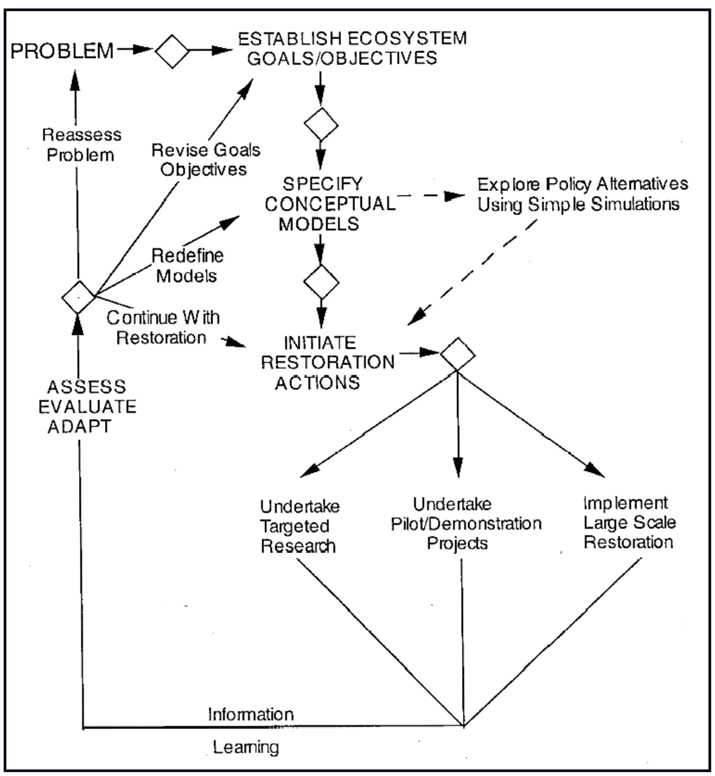
## FIGURE AND TABLE CAPTIONS

## FIGURES

**Figure 1: Two Models of Adaptive Management**



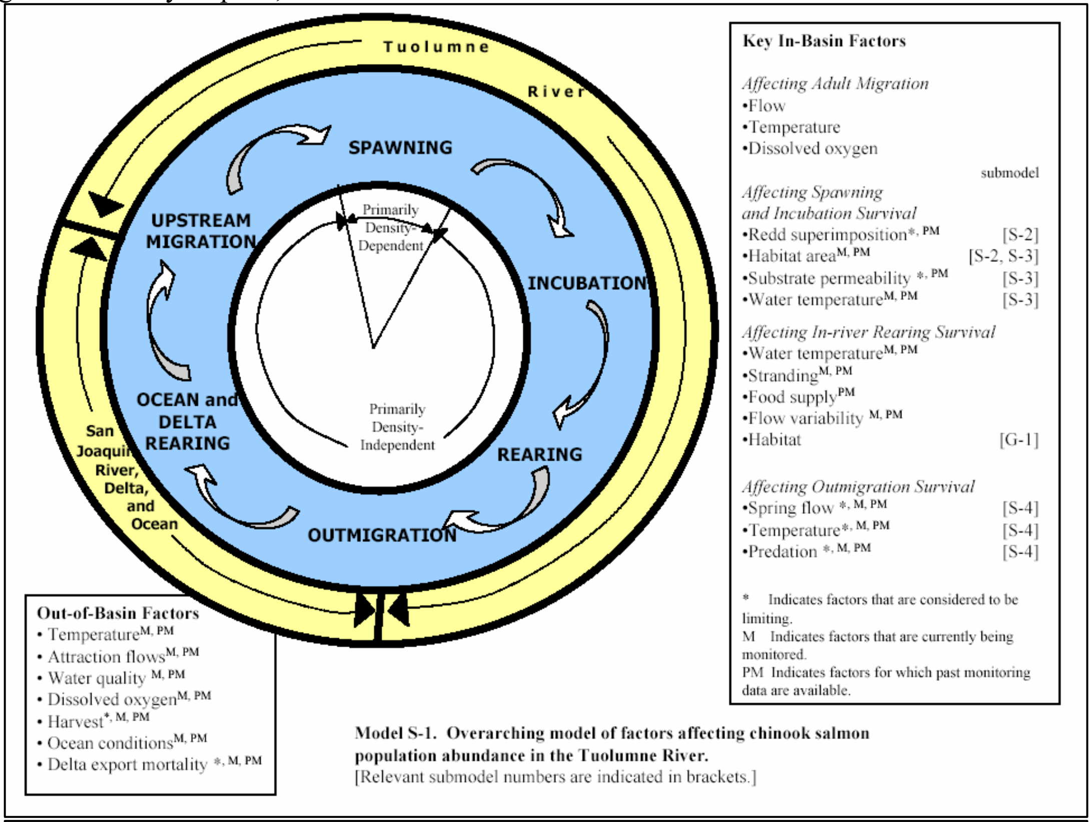

Source: National Oceanic and Atmospheric Administration Coastal Services Center. URL: http://www.csc.noaa.gov/coastal/management/management.htm



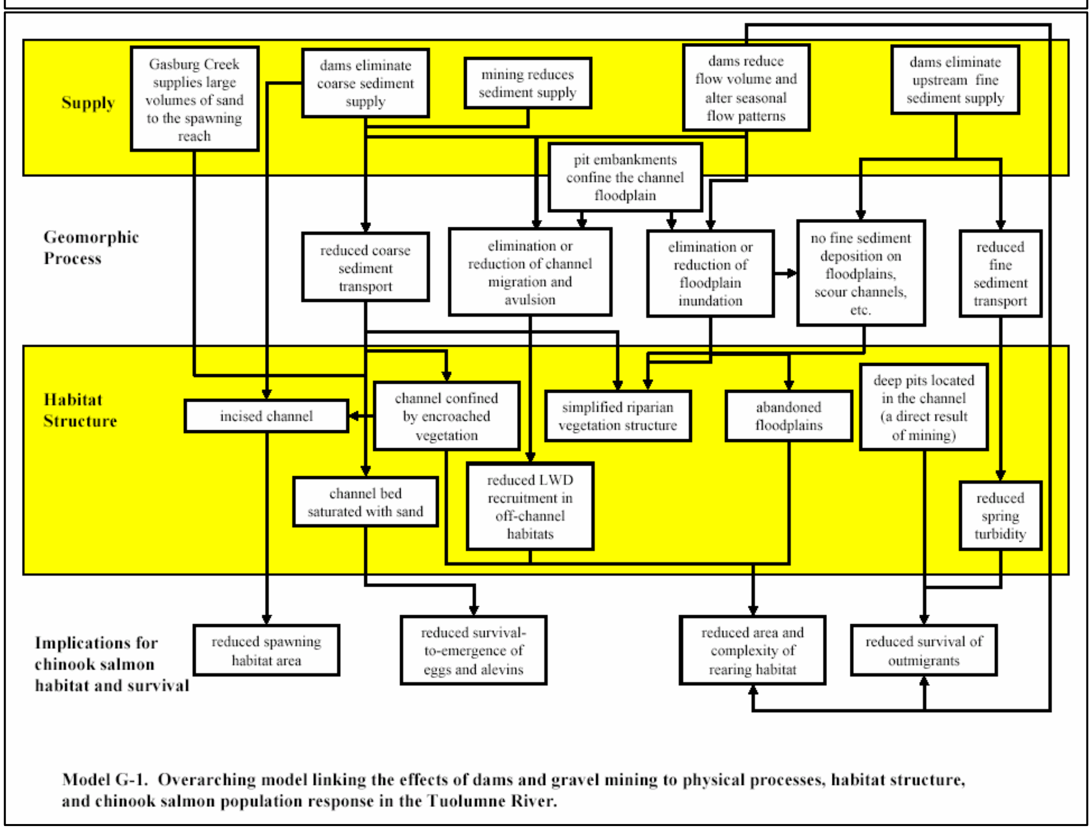

Source: Figure 3-1, CALFED Bay-Delta Program, Strategic Plan for Ecosystem Restoration, July 2000

**Figure 2: Conceptual Models for the Tuolumne River**

Source: Stillwater Sciences, AFRP/CALFED Adaptive Management Forum, Tuolumne River Restoration Program Summary Report , 2001.




**Model S-1. Overarching model of factors affecting chinook salmon population abundance in the Tuolumne River.**
[Relevant submodel numbers are indicated in brackets.]




**Model G-1. Overarching model linking the effects of dams and gravel mining to physical processes, habitat structure, and chinook salmon population response in the Tuolumne River.**

## TABLES

**Table 1: Case Studies Selected**

| Project Code | Project Type | Project Location | Drainage Area (sq. miles) |
|---|---|---|---|
| A | Removal of fish barriers to improve passage | Central Valley, CA | 100-500 |
| B | Riparian revegetation | Central Valley, CA | 100-500 |
| C | Experimental flows | Central Valley, CA | 100-500 |
| D | Riparian and floodplain restoration | Central Valley, CA | 500-1,000 |
| E | Addition of habitat structures, nutrient enrichment | British Columbia, Canada | 100-500 |
| F | Addition of woody debris to mitigate dam enlargement | Coast Range, CA | 10-50 |
| G | Experimental flow release | British Columbia, Canada | 100-500 |
| H | Increased flows, channel rehabilitation, sediment management, upslope watershed restoration | Central Valley, CA | 1,000-5,000 |
| I | Restoration of former mining sites to eliminate predator habitat | Central Valley, CA | 1,000-5,000 |
| J | Environmentally friendly flood control | Urban Bay Area, CA | 5-10 |

**Table 2: Adaptive Management Programs Reviewed**

| Project Code (see Table 1) | Project Location | Drainage Area (sq. mi.) | Primary Project Intent | Restoration Action(s) | Spatial Scale | AM Type | Interviewee Code | Interviewee's Organizational Affiliation |
|---|---|---|---|---|---|---|---|---|
| **A** | Central Valley, CA | 100-500 | Enhance salmonid in-stream habitat | Removal of fish barriers to improve passage | Site | Trial and error/monitor-and-modify | A | State agency |
| **B** | Central Valley, CA | 100-500 | Enhance salmonid in-stream habitat | Riparian revegetation | Site | Passive AM | B | Federal agency |
| **C** | Central Valley, CA | 100-500 | Enhance salmonid in-stream habitat | Experimental flows | Reach and river | Active AM | C1 | Federal agency |
| | | | | | | | C2 | Science consulting firm |
| **D** | Central Valley, CA | 500-1000 | Enhance salmonid in-stream habitat, improve floodplain habitat | Riparian and floodplain restoration | Project and reach | Passive AM | D | NGO |
| **E** | British Columbia, Canada | 100-500 | Enhance salmonid in-stream habitat | Addition of habitat structures, nutrient enrichment | River | Passive AM with control | E | Federal agency |
| **F** | Coast Range, CA | 10-50 | Enhance salmonid in-stream habitat | Addition of woody debris to mitigate dam enlargement | Reach | Trial and error/monitor-and-modify | F | County agency |
| **G** | British Columbia, Canada | 100-500 | Enhance salmonid in-stream habitat | Experimental flow release | Reach | Active AM | G | Provincial agency |
| **H** | Central Valley, CA | 1,000-5,000 | Enhance salmonid in-stream habitat | Increased flows, channel rehabilitation, sediment management, watershed restoration | River | Active AM | H1 | Science consulting firm |
| | | | | | | | H2 | Federal agency |
| **I** | Central Valley, CA | 1,000-5,000 | Enhance salmonid in-stream habitat | Restoration of former mining sites to eliminate predator habitat | Site | Passive AM | I1 | Federal agency |
| | | | | | | | I2 | Science consulting firm |
| **J** | Urban Bay Area, CA | <10 | Flood control | Environmentally friendly flood control | Reach | Trial and error/monitor-and-modify | J1 | State agency |
| | | | | | | | J2 | County agency |

**<u>Table 3: Summary of Major Challenges Encountered</u>**

| | Challenge | Description |
|---|---|---|
| Institutional and Social | Inadequate funding | There is not enough funding available for all steps of the adaptive management process. With limited resources, there is limited flexibility to try different management approaches. |
| | Short-term funding | Grants are typically only for 1-3 years, not enough time for monitoring. |
| | Limited staff | Human resources are generally insufficient for data collection and analysis; staff have little time to share results and learn from other scientists. |
| | Unreliable funding sources | Since much of the funding comes from competitive grants and since priorities of funders change with time, practitioners have little assurance that projects can continue. |
| | Lack of leadership and coordination | Adaptive management efforts are not linked together; there is no formal structure for learning between projects |
| | Traditional resource management values | Managers may fear "failure" and be averse to risk-taking/ experimentation. |
| | Opportunity costs | Experimental design may preclude other potentially beneficial restoration projects that might confound results. |
| | New approach | Adaptive management may be conceptually difficult to understand and implement. |
| | Tension between science and "common sense" | Experiments must continue even when it may be apparent that they are "not working." |
| | Lengthiness of process | Stakeholders/agencies may want to see results more quickly. |
| | Lack of documentation | Overburdened resource managers may not have time to record the details of a project, and valuable information can get lost. |
| Technical and Scientific | Scaling conceptual models and results | It is difficult to translate models and results for a specific project to an understanding of the river system. |
| | Choice of metric | It is difficult to know what metric will adequately track the variable of interest. |
| | Measurement methods | Different measurement methods may be needed for different experiments, but this may lead to results that should not be compared. |
| | Confounding factors | Scientists may not be able to attribute changes to a particular experiment if there are many other variables that may have caused the change. |

**APPENDIX**

## Interview Questions

Defining adaptive management:
- What makes this an “adaptive management” project/program? (What are the specific elements that make this approach adaptive management?)
- How do you define adaptive management? What are the different components of an adaptive management approach?
- Why are you using adaptive management?

Developing the adaptive management program:
- How was your adaptive management component originally envisioned?
- Is the adaptive management program modelled after an adaptive management program elsewhere?
- With unlimited resources, how might your adaptive management approach be different?

Goals and objectives:
- What are the goals and objectives of the project?
- How were these goals and objectives developed and decided? By whom and through what process?
- Are these goals and objectives realistic given the resources available?
- Have goals and objectives changed over time?

Conceptual model:
- Does this project/program involve a conceptual model?

If so:
  - What is the model like? Is it qualitative or numerical?
  - What are the elements?
  - How was it developed?
  - By whom was it developed?
  - Does the model involve the testing of hypotheses? Are these hypotheses based on uncertainties that you want to understand? Are these uncertainties based on causal factors or impacts?
- If not, why not?

Monitoring:
- Does this project/program involve monitoring?

If so,
  - What are you monitoring?
  - What is the relationship between the monitoring program and the hypotheses?
  - What is the time frame for monitoring?
  - How/by whom are data being collected?
  - How/by whom are the data being analyzed?
  - How is data being used to affect management decisions?
- If not, why not?

Stakeholder participation:
- What stakeholders are involved?
- How long have stakeholders been involved?
- How are stakeholders involved in this project? (What is their role?)

Coordination with other projects/programs:

- Have you been involved in sharing information with other similar projects/programs?
- If so,
    - What information have you shared?
    - What information have you received?
    - Has this been beneficial?
- If not, why not?

Ecological and Social Outcomes:

- Are there any ecological outcomes you can attribute to AM?
- Any social outcomes?

Lessons learned:

- What have you learned from the system?
- How have you learned it?
- Which elements of the adaptive management approach are working for this project?
- What have been the major challenges/difficulties in applying adaptive management?
- What are the advantages and disadvantages of using adaptive management?