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The Application of Adaptive Management to Ecosystem Restoration Projects

by Craig Fischenich[1], Craig Vogt[2], and others[3]

OVERVIEW: August 2009 guidance from USACE headquarters, implementing Section 2039 of WRDA 2007, requires that ecosystem restoration projects include plans for monitoring success and adaptively managing ecosystem restoration projects. This Technical Note (TN) summarizes the state of science and practice for adaptive management. In no way should it be perceived as expression of Civil Works policy. It is expected that readers will consult formal Civil Works policy, regulations, and guidance for details regarding required/acceptable practices.

Why apply Adaptive Management to ecosystem restoration projects? The challenges of ecosystem restoration and the philosophy behind Adaptive Management are captured in the following summary statement:

> *Because of the changing conditions and uncertainties, ecosystem stability can only be viewed as a short-term objective. Long-term restoration must be an ongoing process whereby restoration implementation becomes a continuing series of management decisions. Each decision should be based upon a growing pool of research information, updated measurements of ecosystem responses, and evaluations of degrees of progress in reaching a set of goals or targets that have been identified as indicative of ecosystem vitality (Davis and Ogden 1994).*

What is Adaptive Management? Adaptive Management prescribes a process wherein management actions can be changed in response to monitored system response, so as to maximize restoration efficacy or achieve a desired ecological state. The basic steps include:

1. Plan: Defining the desired goals and objectives, evaluating alternative actions, and selecting a preferred strategy with recognition of sources of uncertainty;
2. Design: Identifying or designing a flexible management action to address the challenge;
3. Implement: Implementing the selected action according to its design;
4. Monitor: Monitoring the results or outcomes of the management action;
5. Evaluate: Evaluating the system response in relation to specified goals and objectives; and
6. Adjust: Adjusting (adapting) the action if necessary to achieve the stated goals and objectives.

[1] Research Civil Engineer, ERDC Environmental Laboratory, Vicksburg, MS
[2] Environmental Consultant, Craig Vogt Inc., Hacks Neck, VA
[3] Contributions to this TN were made by several individuals – see Acknowledgments.

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What are the benefits of Adaptive Management? Adaptive Management allows projects to proceed in the face of uncertainty, accelerating project implementation and benefits. Because it eliminates some undesirable outcomes, Adaptive Management also increases the likelihood that restoration projects will achieve full success. It is possible to quantify the costs and some of the benefits of employing Adaptive Management, and this technical note presents one method for characterizing the direct benefits of the process. Indirect benefits are more difficult to quantify, but the knowledge and insight gained from participating in the process are clearly significant.

ADAPTIVE MANAGEMENT FOR ECOSYSTEM RESTORATION[4]

What are the requirements[5] for using Adaptive Management in the ecosystem restoration context?

Paragraph (3)(d) in Section 2039 of WRDA 2007states that "an adaptive management plan will be developed for all ecosystem restoration projects. . . appropriately scoped to the scale of the project." However, it is anticipated that only projects characterized by high uncertainty in achieving results will need to include specific costs and actions for adaptive management. The guidance requires consideration of the costs of monitoring as a project cost (not to exceed 10 years after project construction). On August 31, 2009, CEWC-PB issued a memorandum to commanders and major subordinate commands providing detailed requirements for implementation of Section 2039 of WRDA 2007 (USACE 2009). Essential elements of these guidance documents include the following:

- Rationale and cost of adaptive management and anticipated adjustments will be included in and reviewed as part of the decision document.
- Identified physical modifications will be cost-shared and must be agreed upon by the sponsor.
- The plan should include the rationale for monitoring and AM, metrics for success, performance standards, the nature of proposed adaptive management measures (contingency plans), the cost and duration of monitoring, disposition of information and responsible parties.
- Changes to the adaptive management plan approved in the decision document must be coordinated with HQ USACE.
- Significant changes needed to achieve ecological success that cannot be addressed through operational changes or the adaptive management plan may be examined under other authorities.
- Costly adaptive management plans may lead to project re-evaluation. If very large uncertainties exist or the potential for very large modifications remain, additional planning or evaluation may be required to secure project approval.

4 This Technical Note presents a generalized framework for Adaptive Management that should be scaled in scope and detail depending upon the complexity of the project or program to which it is applied.
5 Readers should consult formal Civil Works policy, regulations, and guidance for details regarding policy and required/acceptable practices.

Adaptive Management Fundamentals:

Definitions and Principles of Adaptive Management. As implied by the term, "Adaptive Management" prescribes a process wherein management actions can be changed in relation to their efficacy at restoring and/or maintaining an ecological or engineered system to/in a specified desired state (Gunderson and Holling 2002, Walters 1986). The desired state (e.g., goals and objectives) might be some precisely defined structural condition or, more realistically, a range of structural conditions, rates of ecological processes, or some description of biotic potential (e.g., productivity). Adaptive Management helps to achieve desired goals by addressing uncertainty, incorporating flexibility and robustness into project design, and using new information to inform decision-making.

A fundamental tenet of Adaptive Management is decision-making under uncertainty. There are many uncertainties associated with restoration of ecosystems; a few examples are included in the text box below.

UNCERTAINTIES IN ECOSYSTEM RESTORATION PROJECTS
Examples from a Coastal Wetlands Restoration Project

Ecosystem water, sediment and nutrient requirements
- Frequency, magnitude, timing and duration of inundation
- Frequency, magnitude, timing and duration of dry conditions
- Annual sediment yield and requirements
- Nutrients required for desired productivity

Current local runoff water quantities and quality
- Distribution of flow by time and quantity
- Water quality based on permitted discharges
- Flow path through channels and ecosystem

Ecosystem responses from application of water, sediment, and nutrients
- Growth curves based on hydroperiod and nutrient application
- Litter production based on nutrient and water levels
- Tree propagation in relation to regulated hydroperiod
- Effects of salinity changes from saltwater intrusion due to SLR

Several definitions for Adaptive Management have been developed by various natural resource management agencies and organizations (e.g., Williams et al. 2007, NRC 2004). The National Research Council provides the conceptual basis for Adaptive Management that was used in this USACE technical note:

> "Adaptive Management promotes flexible decision-making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood.
>
> - Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process.

- Adaptive Management also recognizes the importance of natural variability in contributing to ecological resilience and productivity.
- It is not a "trial and error" process, but rather emphasizes learning while doing (emphasis added).

Adaptive Management does not represent an end in itself, but a means to more effective decisions and enhanced benefits. Its true measure is in how well it helps meet environmental, social, and economic goals, increases scientific knowledge, and reduces tensions among stakeholders" (NRC 2004)."

Based upon the above discussion, and for the purposes of this technical note, Adaptive Management is defined as:

A formal science-based approach to undertaking goal-directed actions with uncertain outcomes, and evaluating their results in order to direct future actions. Simply stated, adaptive management is doing while learning in the face of uncertain outcomes.

PRINCIPLES OF ADAPTIVE MANAGEMENT

1. *Management flexibility is incorporated into the design and implementation of programs or projects.*
2. *Scientific information obtained through continued monitoring is used to evaluate and manage uncertainties to achieve desired goals and objectives.*
3. *Scientific information is introduced into the decision-making process and guides managers during and after project implementation.*
4. *Projects and programs can be implemented in phases to allow for course corrections based on new information.*
5. *Interagency collaboration and productive stakeholder participation are key elements to success.*

Adaptive management can be *active*, wherein the project is specifically designed to address key uncertainties (posed as hypotheses), such that implementation is treated as an experiment and the results inform future implementation or operational decisions. Conversely, AM can be *passive*, in which case select performance metrics are monitored but the project is implemented without the intent of a rigorous testing of hypotheses. In either case, necessary adaptive actions should the project fail to perform as intended can sometimes be determined ahead of time. These pre-determined responses are referred to as *contingency plans*.

What are the steps of Adaptive Management? Adaptive Management adds several considerations to the traditional planning process, including the identification of needed monitoring before, during and after project construction; the identification and assessment of performance

measures and action criteria; and the determination of what adjustments to the project restoration actions may be needed or whether the project is considered complete based upon achieving the expected outcomes. Plans must also be made for the acquisition and management of data, as well as the analysis and decision-making for implementing management decisions. These additional requirements force planning teams to contemplate objectives and project performance at a level of detail not previously considered, with several associated benefits.

The basic steps of the Adaptive Management process are shown in Figure 1 and include:

1. *Planning* a program or project, including the development of an AM plan;
2. Designing the corresponding project;
3. Building the project (construction/implementation);
4. Operating and maintaining the project;
5. Monitoring selected parameters to measure project performance; and
6. Assessing the results of monitoring, which will lead to decisions to:
7. Continue project monitoring with no adjustment; or
8. Adjust the project if goals and objectives are not being achieved; or
9. Determine whether the project has successfully produced the desired outcomes and is complete.

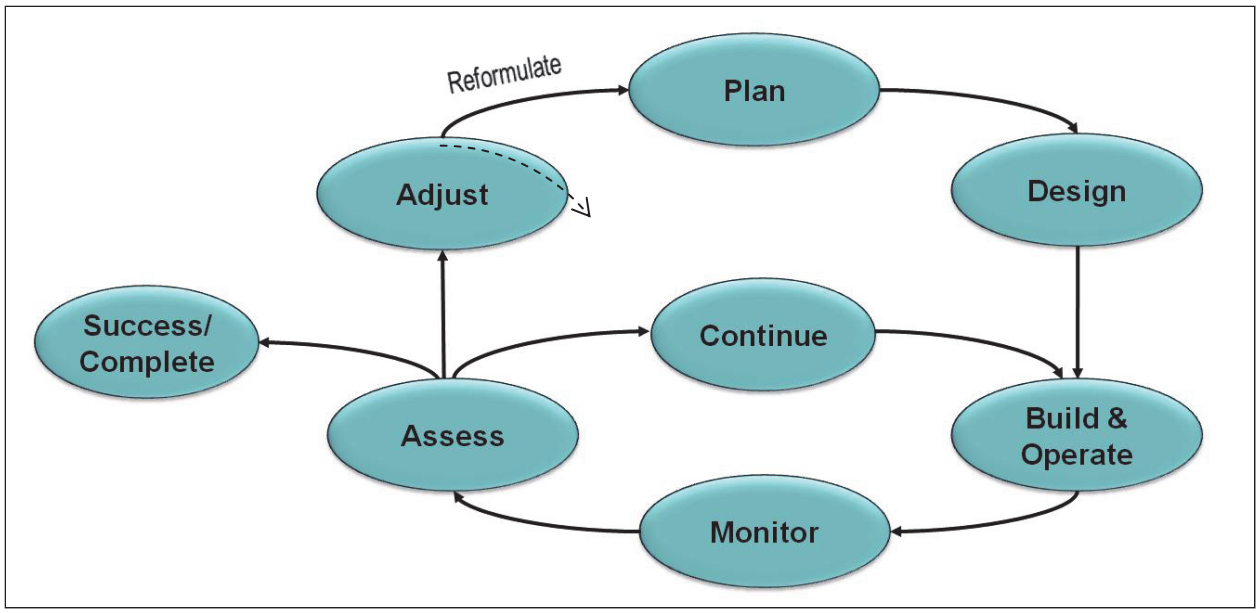

Figure 1. Steps in Adaptive Management.

The *Adjusting* step refers to Adaptive Management as opposed to routine maintenance. The distinction is that Adaptive Management actions result in a change to the design or operation, while maintenance restores the project to its design condition. Modifications to the current

project should be consistent with the Adaptive Management Plan. If further adjustments are required beyond the current authority, a new plan might be required (i.e., reformulation). In this respect, the process can be regarded as iterative.

Adaptive Management is not a trial and error process; it requires considerable attention "up-front" during project planning:

- Using trial and error to implement projects is highly inefficient because monitoring and assessment are not focused on the critical causalities and uncertainties identified in the planning stages. This limits learning potential and increases the probability of repeated mistakes on existing and future restoration projects.
- Alternatively, Adaptive Management uses performance-related hypotheses and directed monitoring and assessment to confirm and improve understanding of ecological processes and helps explain why the goals and objectives were or were not achieved.
- Establishing the performance hypotheses, identifying the monitoring requirements, and formulating needed response actions must be accomplished concurrently with evaluating alternatives because Adaptive Management can influence which alternative is preferred.

Adaptive management promotes an open and inclusive atmosphere in order to facilitate interagency and stakeholder participation.

- The full range of stakeholder interests and values are acknowledged; this ensures that new ideas are considered in the decision-making process.
- By building trust among stakeholders, the likelihood of support is increased for the restoration project by providing a common vision of success, while avoiding both surprises and stalemates through effective and timely use of conflict resolution.
- Costly delays from legal actions and policy clarifications may be reduced or eliminated by promoting stakeholder engagement and interagency collaboration.

What are the benefits of using an Adaptive Management approach? Using an Adaptive Management process requires planners, managers, and stakeholders to examine the proposed management actions and consider a range of potential problems and outcomes at a level of detail not required elsewhere in more traditional studies. Resultant benefits of Adaptive Management include:

- The development of flexible alternatives improves the likelihood of success across a broad range of future conditions. By addressing uncertainty in all phases of planning, design, construction, and operations, built-in flexibility helps ensure efficient and effective restoration.
- The best available science is used to help plan, design, construct, and operate programs and projects.
    - Single or multiple hypotheses can be tested to address the uncertainties inherent in project implementation. Hypotheses relate to well-defined performance measures and are

linked to monitoring and assessment, which measure the response of the system to implementation.

- The information learned from this process is then conveyed to managers and stakeholders to support decision-making and evaluate progress towards achieving goals and objectives.

- Because Adaptive Management is an iterative process, any new information gathered during monitoring, assessment, and implementation continuously enters into the decision-making process to improve performance.
- Adaptive Management provides a forum for dialogue between scientists, managers and stakeholders to interpret the monitoring and assessment results. This forum serves to inform both policy and management decisions and allows managers to seek clarification about scientific and technical questions that may affect implementation.
- Adaptive Management promotes long-term cost savings by incorporating flexibility and robustness into planning and implementation. The management flexibility produced by vigorous project design lowers costs by reducing the likelihood that existing projects will require costly adjustments. Adaptive Management also increases the benefits derived from restoration projects because it eliminates undesirable outcomes.

One method for quantifying the benefits of adaptive management is based on the recognition that, for any project, there are a number of possible outcomes with associated benefits (and costs). Figure 2 is an example of benefits described in terms of alternative trajectories (represented by the two different dashed lines).

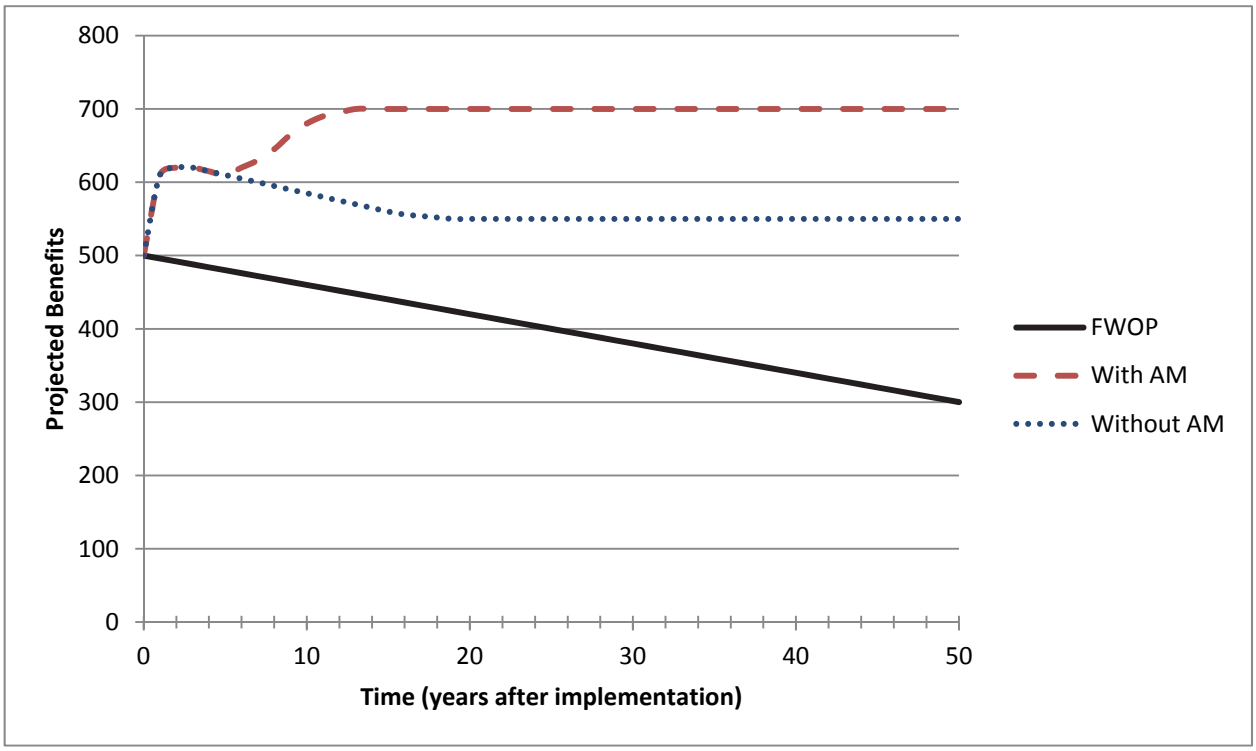

Figure 2. Quantification of the benefits of Adaptive Management.

Through Adaptive Management actions, we can eliminate some undesirable outcomes. In this example, the undesirable response is represented by the blue dot line. In year five, it is recognized that the response trajectory is not as hoped, so adaptive actions are taken. The red dashed line represents conditions following the Adaptive Management action. The benefits for each case are determined by calculating the net difference between the alternative benefits and the future without-project condition (FWOP), averaged over the project life (in this case, 288 average annual benefit units for the case with Adaptive Management and 165 units without). The benefit of the Adaptive Management action is the net difference between the two project outcomes (in this case, 123 average annual benefit units).

Alternative approaches for characterizing the benefits of Adaptive Management are possible. One more comprehensive but complex method involves identifying and assessing a range of possible outcomes for each alternative (Figure 3). The expected benefits can be regarded as the sum of the products of the individual outcome benefits and probability for each alternative trajectory. In the example shown in Figure 3, there are eight possible outcomes; the first number in the column adjacent to each line is the probability of that particular outcome.

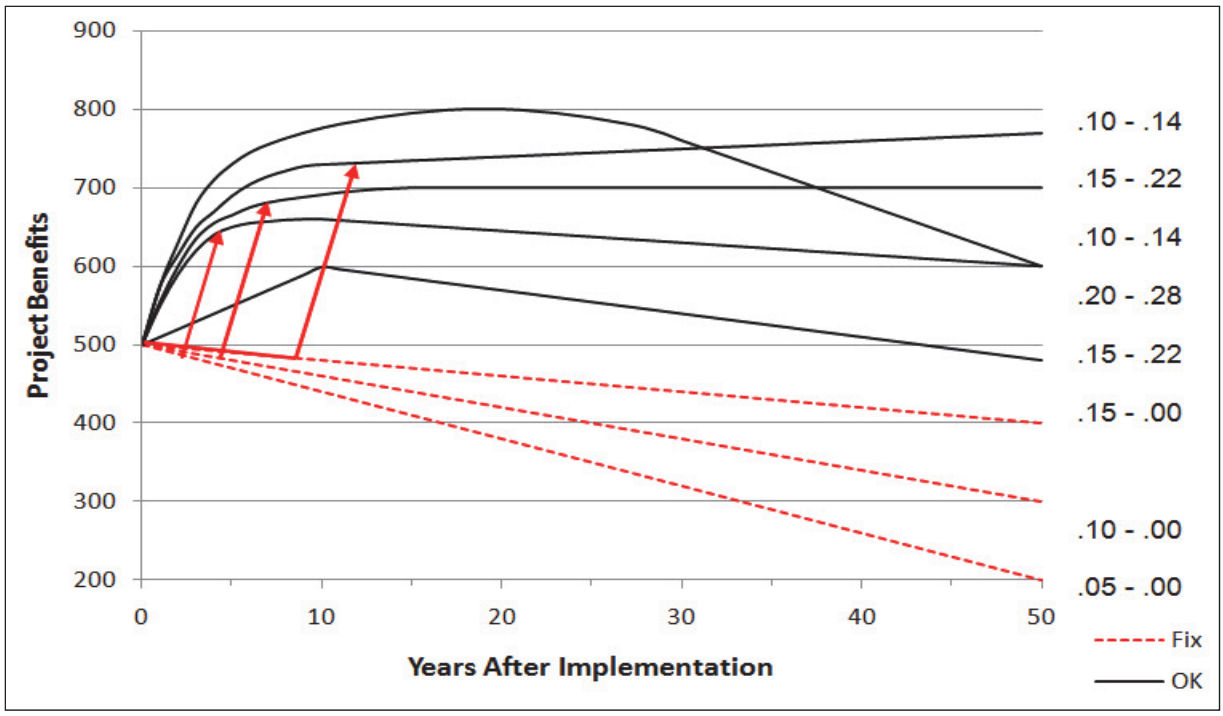

Figure 3. Alternative approach to characterizing Adaptive Management benefits.

Eliminating the undesirable outcomes (represented by red dashed lines) reduces the field to five trajectories, and each outcome has a new probability (represented in the second column to the right). Without Adaptive Management, we sum all eight outcomes, but with Adaptive Management only the top five (with greater benefits and higher probabilities). Regardless of the method used, the costs of implementing Adaptive Management must be factored into the analysis when evaluating the overall net benefits.

In many cases, it will not be possible to identify the potential outcome trajectories and the associated probabilities *"a priori."* However, the figures and discussion provide a conceptual basis for assessing the value of Adaptive Management and can serve to guide efforts to quantify the return on investment. The planning team should attempt to describe the output trajectories and assign probabilities to each as part of the AM plan formulation process. It is understood that there may be considerable uncertainty associated with these assessments, but that uncertainty can be described — sometimes quantified — and factored into decisions.

Developing the Adaptive Management Plan: The Set-up Phase. Adaptive Management planning consists of an initial set-up phase that addresses the fundamental components of Adaptive Management (shown in Figure 4), as well as the initial formulation of an implementation plan discussed later. It requires considerable, deliberative assessment on the part of the planning team and stakeholders as to possible outcomes and responses for each alternative. The product of the set-up phase is a monitoring and Adaptive Management Plan ready for implementation. The set-up phase is typically addressed iteratively with a draft plan prepared during feasibility studies and a refined plan prepared during the design phase. Cost estimates are also prepared in feasibility and refined during design. The activities in Figure 4 occur within the "Plan" step of the overall process as shown in Figure 1.

There are clear linkages between planning for Adaptive Management and the traditional USACE planning process; Figure 5 associates the components of Adaptive Management (from Figure 4) with the six-step USACE planning process. It is important to recognize that both the costs and benefits of Adaptive Management can influence alternative selection; adequate characterization of these parameters is therefore necessary in the early stages of the planning process and not as an afterthought following alternative selection. Not shown in Figure 5 but part of the planning process is the need to estimate costs associated with implementation of the plan.

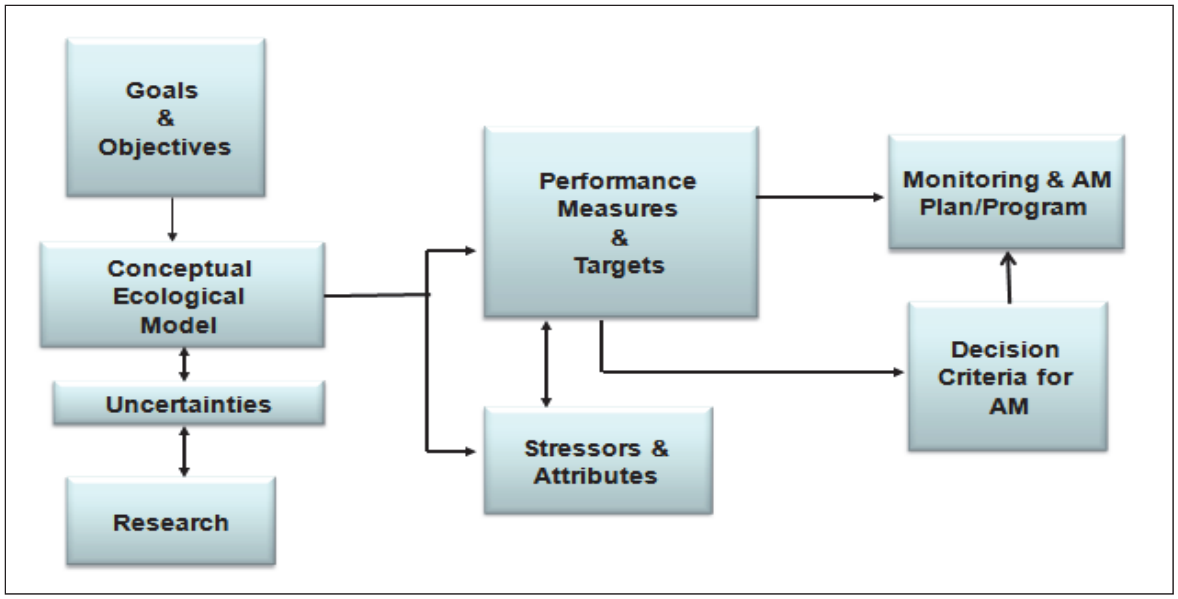

Figure 4. Set-up phase of Adaptive Management planning.

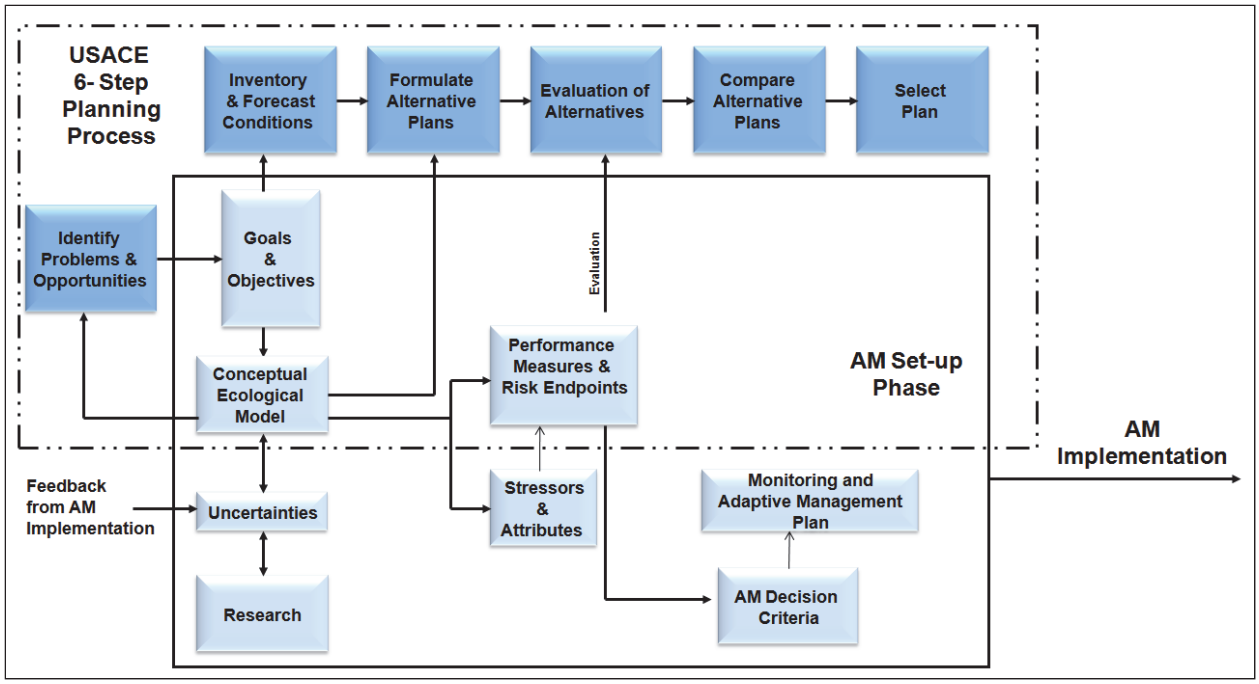

Figure 5. USACE six-step planning process and set-up phase for Adaptive Management.

Adaptive Management Team: The initial step in the Adaptive Management planning process is the identification of individuals who will be responsible for developing and implementing the Adaptive Management Plan. For the sake of convenience and consistency in this technical note, the individuals are referred to as the Adaptive Management Team (AMT). The AMT supports the Project Delivery Team (PDT), and in most cases would consist of a subset of the PDT.

CREATING THE ADAPTIVE MANAGEMENT TEAM

- Identify individuals to serve on the Team
- Determine policies for terms of service, substitution of members, and selection of new members
- Plan for adequate technical, financial and logistical support services

Adaptive Management is Applicable and Potentially Useful if:

- Project outcomes are uncertain;
- Response to restoration can be reasonably measured & adverse or sub-optimal response identified; and
- Alternative (i.e. adaptive) actions are available and implementable.

Depending on the nature and complexity of the ecosystem restoration project, the AMT might be expanded to include individuals from other participating federal (e.g., National Marine Fisheries Service, Fish and Wildlife Service) or state resource or regulatory (e.g., USEPA) agencies, as well as stakeholder organizations. For particularly complex projects or programs, the AMT could have several sub-teams, such as a technical team, a management team of senior managers, and a dispute resolution team of agency leaders. The important point is that the individuals responsible for developing and performing adaptive management as well as their

specific roles and responsibilities are clearly identified at the outset in the Adaptive Management Plan and participate throughout the plan implementation (see also Bartell 2006).

GOALS AND OBJECTIVES: In the planning process, the USACE planning team (i.e., PDT) examines project alternatives in terms of anticipated outcomes relative to the planning goals and objectives. The initial planning step (i.e., identify problems and opportunities) provides the first opportunity to integrate Adaptive Management planning. Not all projects or alternatives lend themselves to Adaptive Management, and the AMT will generally need to evaluate proposed project objectives and alternatives from the perspective of uncertainties, risks, and potential for post-implementation modification.

- Based upon the specific authorization, and in collaboration with stakeholders, the USACE defines the restoration goals and objectives to address through specific management or restoration alternatives.
- The USACE planning process identifies project alternatives and management actions to achieve specified goals and objectives in relation to desired future conditions. During the six-step planning process, the USACE identifies environmental conditions that it wishes to achieve as well as risks to be avoided, minimized, or mitigated.
- Planning for Adaptive Management demands a critical review of each objective to determine appropriate metrics, establish success criteria, and consider likely restoration trajectories for each alternative. In cases where the outcome is uncertain, and where the potential exists to adjust the project if it fails to respond as hoped, performance targets and associated management actions are identified.
- Importantly, the planning phase of Adaptive Management provides additional opportunities for interaction among USACE planners, stakeholders, and the AMT. This process can help ensure the development of viable management and restoration alternatives to achieve specified goals and objectives that are compatible with Adaptive Management.

EXAMPLE PROJECT GOALS AND OBJECTIVES

- Promote water distribution in the southeastern portion of Maurepas Swamp to move stagnant water out of the system
- Facilitate swamp building at a rate greater than swamp loss (due to subsidence and sea level rise) by increasing sediment input and swamp production to maintain or increase elevation in the swamp
- Increase the durations of dry periods in the swamp to improve baldcypress and tupelo productivity and to increase seed germination and survival of these key species
- Improve fish and wildlife habitat in the swamp and in Blind River

USACE, Convent/Blind River 2009

CONCEPTUAL ECOLOGICAL MODELS AND UNCERTAINTIES: Formulating an effective ecosystem restoration project requires an understanding of 1) the underlying cause(s) of degradation; 2) how causal mechanisms influence components; and 3) how the effects may be reversed through intervention. These elements, then, should form the nucleus of any conceptual model used for project formulation, and are, in fact, common elements of most effective conceptual ecosystem models (Fischenich 2008).

Conceptual ecological models are descriptions of the general functional relationships among essential components of an ecosystem. They tell the story of "how the system works" and, in the

case of ecosystem restoration, how restoration actions aim to alter those processes or attributes for the improved function or sustainability of the system. An understanding of the target ecosystem (e.g. Figure 6) is paramount to planning and constructing achievable ecosystem restoration projects. As such, conceptual ecological models can provide the Adaptive Management Team with:

- A clear depiction of system components and interactions;
- A diagnosis of underlying ecosystem problems and causes of degradation;
- Isolation of cause and effect relationships;
- Identification of actions most likely to demonstrate ecosystem responses; and
- An effective communication tool.

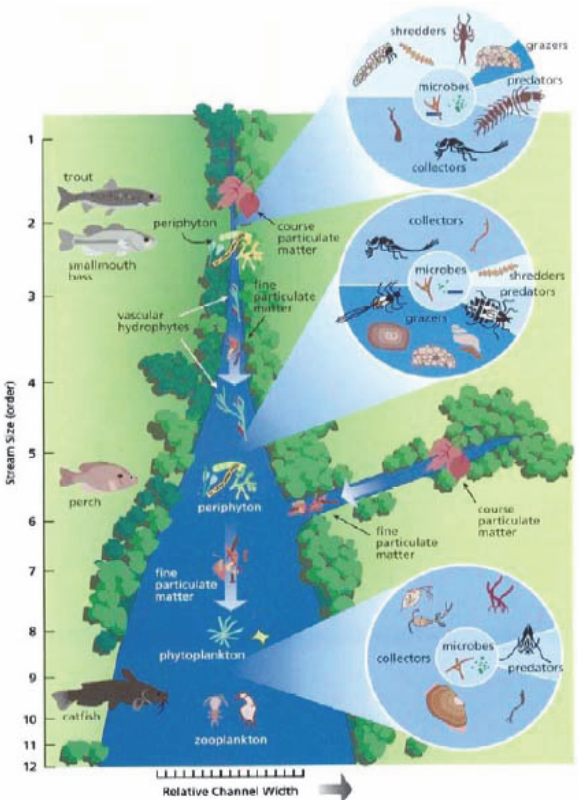

Figure 6. Ecologists use the River Continuum Concept (Vannote et al. 1980) as a scientific framework for describing predictable spatial change in parameters for flowing ecosystems.

Maddox et al. (1999) suggested that conceptual ecological models play three significant roles in monitoring.

1. Models summarize the most important ecosystem descriptors, spatial and temporal scales of critical processes, and current and potential threats to the system. They provide feedback to scientists, and help them formulate goals and objectives, indicators, management strategies, results, and research needs. Models also facilitate open discussion and debate about the nature of the system (including stressors and attributes) and key management issues.
2. Models play an important role in determining measures and indicators for monitoring. Due to the fact that models are statements of important physical, chemical, or biological processes, they identify aspects of the ecosystem that should be measured.
3. Models are invaluable tools to help interpret monitoring results and explore alternative courses of management. An explicitly stated model is a summary of current understanding of and assumptions about the ecosystem. As such, it can motivate and organize discussion and serve as a "memory" of the ideas that inspired the management and monitoring plan.

Conceptual models can also help identify sources of variability and uncertainty that can influence the success of adaptive management.

- In this technical note, variability refers to natural patterns of spatial and temporal heterogeneity that cannot be reduced by additional sampling. Variability reflects the dynamic nature of ecological and environmental systems. Sampling methods and designs should accurately and precisely quantify variability.

- Uncertainty refers to bias and imprecision introduced into monitoring and Adaptive Management planning from several sources, including, for example,
  (1) inadequate sampling designs, improper methodologies in sample collection, and errors in sample processing or data analysis;
  (2) poor data management and miscommunication; and
  (3) incomplete scientific understanding of the managed ecosystem.

The implications of these uncertainties on the overall effectiveness of the Adaptive Management process should be quantified to the extent possible during the set-up phase. The establishment of feedback mechanisms that translate the results of monitoring and assessment into scientifically informed decision-making is fundamental to reducing uncertainties and increasing the likelihood that management goals and objectives will be achieved with help from Adaptive Management.

ACTION CRITERIA: Action criteria are the specific values of monitored parameters used in evaluating program and project performance. Importantly, these criteria determine if the monitoring results support continued implementation of the project as designed or if adaptive actions should be undertaken. Action criteria differ from *success criteria*, which are used to help the Division Commander determine when ecological success has been achieved. Action criteria should be developed for both performance measures and risk endpoints, such that performance hypotheses about project outcomes can be evaluated to determine if adjustments are needed in management measures.

A key to developing the monitoring plan is to match the level of the monitoring effort to the needs of management for decision-making.

Performance measures (*or targets*) refer to the desired outcomes of program and project implementation. Performance measures are derived from stressors and attributes identified in the conceptual models and should: (1) be measurable; (2) have a relatively strong degree of predictability (*i.e.*, targets specified by predictive models or by best professional judgment); (3) change in response to project implementation; and (4) verify progress and evaluate hypotheses through monitoring and assessment.

Risk endpoints refer to undesired effects of management actions; they are essentially measures of negative project performance (i.e. adverse impacts or constraint violations). The concept of risk includes (1) the possibility that the anticipated project outcomes will not be achieved, (2) the potential that some other unexpected, undesired (and

EXAMPLE PERFORMANCE MEASURES, RISK ENDPOINTS, AND ACTION CRITERIA

Objectives/Constraints	Units Measured	Action Criteria
Performance Measures		
Wetland hydrology	Days inundated	>30 days during Jul-Sep
Population size of desired species	# individuals or biomass	50% incremental increase
Plant community diversity	Simpson diversity	15% incremental increase
Risk Endpoints		
Establishment of an Invasive species	Presence/absence	No invasive species
Violating nutrients	Molar concentration	Water quality standards
Dissolved oxygen	mg/L	> 4.5 mg/l

perhaps irreversible) outcome will occur, or (3) that there are certain adverse impacts to be avoided, minimized, or mitigated during project implementation. The first two aspects of risk result from the fact that ecosystems are inherently variable and incompletely understood. As a result, expected outcomes of management actions are not entirely certain. The third aspect of risk relates to defining risk endpoints; i.e. characterizing project constraints that cannot be violated.

Action criteria (also referred to as Adaptive Management triggers) are used to determine if and when Adaptive Management actions should be implemented. These criteria can be specified as single values or ranges of desirable outcomes. They can be qualitative or quantitative based on the nature of the performance measure and the level of information necessary to make a decision, but should be quantified when possible. Because of the long response time for many ecosystem restoration efforts, action criteria are often based upon trajectories or rates of change for metrics that are indicative of ecological function.

Desired outcomes can be based on reference sites, predictions using ecological models, informed judgment of subject matter experts, or in some cases comparison to historic conditions. Action criteria can usually be specified during the feasibility stage and need only minor adjustment at later study phases. The implementation plan should describe mechanisms to adjust Action criteria (and perhaps success criteria) that ultimately prove inappropriate.

MONITORING: The key planning products related to monitoring are (1) a detailed monitoring plan and (2) a data management plan that serve as integral parts of the overall Adaptive Management Plan. These will by necessity be formulated iteratively, and should be sufficiently detailed at the feasibility stage to permit good cost estimates, whereas they should be ready for implementation at the close of the PED stage.

Effective monitoring is central to the Adaptive Management process.

- The monitoring plan should first identify appropriate metrics given the goals and objectives.
  - The monitoring program should identify one or more direct metrics (i.e., measured parameters) that apply to each project performance measure and risk endpoint and its associated action criteria.
  - Observed changes in the metrics or endpoints should be unambiguously related to specific management or restoration actions.
  - The level of detail for any selected parameter to be monitored can be reasonably guided by its contribution to assessment and decision-making. For example:
    - If a risk endpoint is to minimize the probability of increased algal abundance (i.e., blooms), measures of total chlorophyll might be sufficient for decision-making.
    - Alternatively, if impacts on algal community structure (e.g., diversity) define the risk endpoint, then more intensive sampling and expensive enumeration of individual algal taxa would be required.
  - The selection of direct measures that are supportive of several performance standards can improve efficiency and cost effectiveness. Direct measures are generally preferred to surrogates or indirect measures, but both are often required.

- The monitoring plan should next identify the relevant technical methods to be used in acquiring the necessary data and information for each of the monitored measures and endpoints.
  - One or more methods for monitoring should be identified for each performance measure or risk endpoint.
  - The methodologies should include descriptions of sampling designs (i.e., locations, frequency) sampling procedures, sample storage and preservation, and processing of samples to generate data.
- Degrees of required accuracy and precision (i.e., data quality objectives) should be defined for each performance measure and risk endpoint.
  - The monitoring plan should define the sampling methods and procedures required to develop data of sufficient quality (i.e., accuracy, precision, statistical power) for use in decision-making.
  - The decision-making process should determine the associated statistical power required for each monitored parameter. As a result, data quality may be defined differently for each performance measure or risk endpoint. For example, demonstrating simple presence-absence of a species would require less of a monitoring investment than determining quantitative changes in the abundance of an existing species.
  - Given an initial estimate of sample variance, the number of sample locations and frequency of sampling should be determined for each measure and endpoint; standard statistical procedures are available to calculate the number of samples required to obtain a specified level of performance for hypothesis testing. Guidance for this and more details for monitoring requirements are addressed in Conyngham (2010).

DATA MANAGEMENT PLAN: A data management plan should be developed to support the monitoring and Adaptive Management application. The data management plan should be incorporated into the overall Adaptive Management Plan, either in the main body of the plan or as an appendix.

- Data management includes the collation, storage/retrieval, analysis, summarization, and communication of monitoring results and related information (e.g., published information, model results) used in support of Adaptive Management.
- For particularly complex projects or programs, individuals with responsibility for data management activities (data managers) may be identified during the set-up phase of Adaptive Management. .

The Data Management Plan should (1) identify the types of data and information to be included in the data management system, (2) establish protocols for QA/QC and include documentation in the data base, (3) establish convenient formats for storing and retrieving data, and (4) guarantee the preservation of the data (i.e., backup versions, electronic and/or hard copy).

- The data management system may serve as an archive for an Adaptive Management program. For example, copies of AMT meeting agendas, meeting notes or minutes, presentations made at AMT meetings, and records of decisions made by the AMT might be maintained in the data management system.

- The data management activities generally include providing monitoring results, data analysis and summarizations as needed by the AMT.
- The data management activities should support effective communication by the AMT to interested stakeholders and the general public.

COSTS OF DEVELOPING AND IMPLEMENTING ADAPTIVE MANAGEMENT PLANS:

ELEMENTS OF THE COST ESTIMATE

- Development of the adaptive management plan
- Monitoring
  - Planning and management
  - Data collection
  - Database development and management
- Implementation of adaptive management program
  - Management of program
  - Assessment
  - Decision-making
- Management actions

The costs associated with implementing the monitoring and Adaptive Management Plans should be estimated based on currently available data and information developed during plan formulation as part of the feasibility study. Because uncertainties remain as to the exact project features, monitoring elements, and Adaptive Management opportunities, the initial estimated costs will likely need to be refined during the PED stage in conjunction with the development of the detailed monitoring and Adaptive Management Plans.

THE ADAPTIVE MANAGEMENT PLAN: A comprehensive Adaptive Management Plan includes both the set-up phase and the implementation phase of the project. The detailed outline on the left is presented as an example for use in an Adaptive Management Plan, and can be adjusted or scaled as needed to fit the needs of a particular project or program.

An Adaptive Management Plan should identify how all of the Adaptive Management components work together and how monitoring and the associated action criteria link to potential management options in the event it's necessary to adjust project implementation. An initial list of possible Adaptive Management actions should be defined in the plan. If the need for a specified adjustment is anticipated due to high uncertainty in achieving the desired outputs/results, the nature and cost of such actions should be explicitly described in the Adaptive Management Plan and program/project decision document.

The Adaptive Management Plan should serve as an open (i.e., generally available) and transparent document that describes each specific Adaptive Management application. It will by necessity often vary in level of detail between the feasibility and PED stages of a project, and depending on the overall project complexity and uncertainty.

EXAMPLE ADAPTIVE MANAGEMENT PLAN
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IMPLEMENTATION OF THE ADAPTIVE MANAGEMENT PLAN: Implementation describes how the Adaptive Management Plan will be put into action (Figure 7). As part of the Adaptive Management planning phase, the AMT should broadly define how to implement the proposed Adaptive Management Plan. The governance structure is critical to successful implementation, and will necessarily vary depending upon the requirements for any given project. Although Figure 7 may appear complicated, the implementation steps can be briefly stated as:

1. Results of the ongoing monitoring programs are collated and analyzed by the AMT to assess whether any performance measures or risk endpoints are triggered.
2. If none of the action criteria are triggered, the Adaptive Management process can simply continue with the current monitoring programs until the next evaluation is performed.
3. If action criteria are triggered, the AMT evaluates the circumstances and decides to implement prescribed adjustments to the management actions, to undertake additional monitoring or study, or to redress the performance standards or risk endpoints that have not been met. This approach permits flexibility in interpreting monitoring results and allows for adjustments to the process and criteria as warranted.
4. Following resolution of the AMT recommendations for adjustments to the management actions, the Adaptive Management process continues by cycling back to step 1.

DEVELOPMENT AND USE OF OPERATING PROCEDURES: Implementation requires the formulation of standard operating procedures that document how the Adaptive Management Plan will operate. The degree of formality and level of organizational detail included in the Adaptive Management operating procedures will, by necessity, vary among applications of Adaptive Management. The intent of developing and documenting operating procedures is to establish a process that can be followed in a consistent manner independent of future changes in the composition of the AMT.

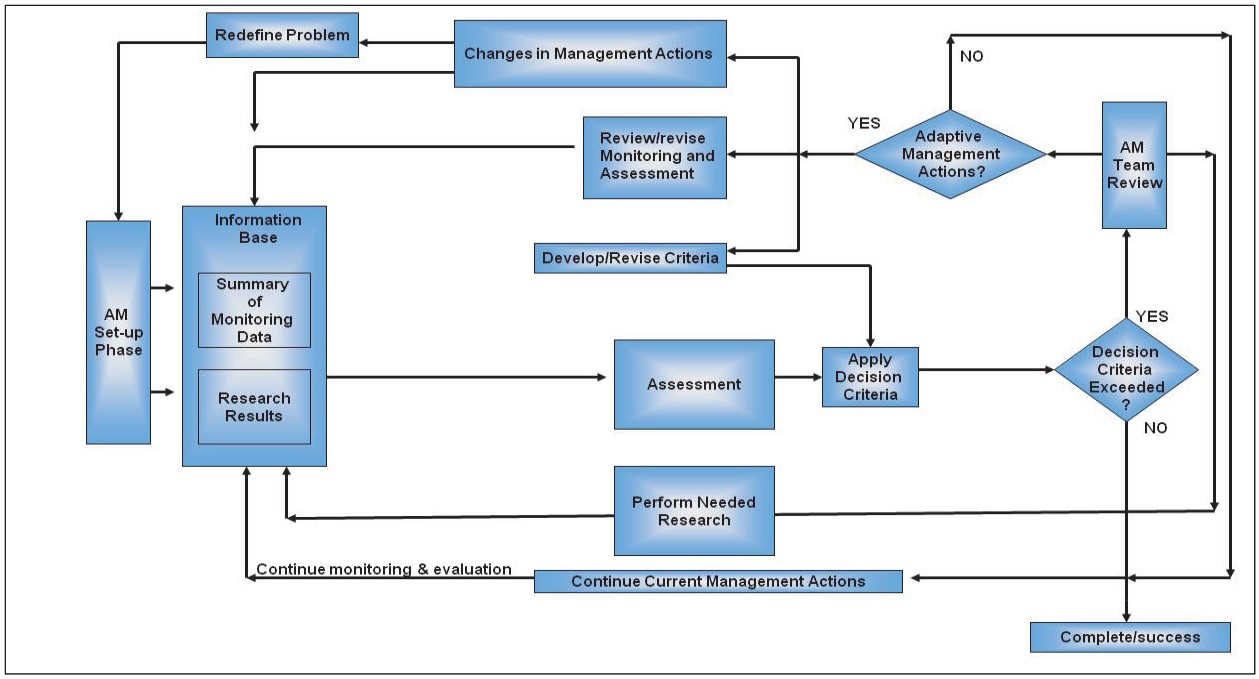

Figure 7. Implementation phase for Adaptive Management.

INFORMATION BASE: Decisions during the implementation phase are based on information that includes existing data and information from the development of the Adaptive Management Plan and the results of monitoring efforts, as well as additional scientific and technical knowledge accumulated during the course of the adaptive management process. The results of assessments and decision-making that occur during the Adaptive Management process – as well as any other pertinent knowledge developed – should be documented and archived as part of the information base (Figure 7).

ASSESSMENT: Assessment is the process by which the results of the monitoring efforts are evaluated and compared to the action criteria that reflect the goals and objectives of the management or restoration action (Figure 6). The Adaptive Management Plan should specify the frequency and scheduling of assessments and consider the relevant temporal scales of the performance measures and risk endpoints, the time required to obtain sufficient monitoring results and analysis for meaningful comparisons with the action criteria, and the consequences (ecological, socioeconomic, political, stakeholder) of variances with action criteria. Other important considerations include:

- Methods for data analysis and summarization should be identified in developing the assessment process.

PLANNING FOR ASSESSMENTS IN ADAPTIVE MANAGEMENT

- Identify persons responsible for performing assessments
- Identify methods for comparing monitoring results with action criteria
- Define frequency of assessments
- Develop documentation for results of assessments
- Communicate assessment results to managers and decision-makers

The nature and format (e.g., qualitative, quantitative) of these comparisons are defined in this step.

- It is important that the Adaptive Management Plan identify those individuals or organizations who will be undertaking the assessment.
- Communicating the results to identified managers and decision-makers is part of the assessment step.
- Documentation of the assessments is also important. Such documentation should include such elements as the qualitative or quantitative assessment methods and summaries of meetings in which assessments were performed. The results of monitoring and their comparisons with action criteria should be preserved, for example, in the form of tables, figures, and supporting text for each assessment.

DECISION-MAKING PROCESS: The process whereby the results of the assessment will be used to make decisions concerning program/project management is typically specified in the Adaptive Management Plan. Key elements include the following, when possible:

- Who is responsible for making the decisions
- How the decision-making group operates
- What information is presented to decision-makers and by whom
- How decision-makers will use the information to identify, develop, and analyze options; and
- How recommended changes are made, reviewed, approved for implementation, and reported.

For example, decisions might be reached autocratically, through consensus or by voting. In either case, the decision-making process should provide opportunity to document minority or dissenting points of view. Importantly, the decision-making process should include provisions for the resolution of conflicts that might arise during the course of Adaptive Management.

DOCUMENTATION OF ADAPTIVE MANAGEMENT: One of the most important aspects of an Adaptive Management process is documentation. Adaptive Management emphasizes an open and transparent management practice wherein the results of monitoring, assessment, and decision-making are routinely and consistently documented. The set-up phase and the resulting Adaptive Management Plan should specify the provisions for regularly documenting Adaptive Management.

CONCLUSIONS: Adaptive Management can be an efficient and cost-effective management process in situations where management goals and objectives are clear, yet the potential outcomes of management actions are uncertain. Most importantly, management actions can be adjusted in response to knowledge gained from monitoring project performance. Properly used, Adaptive Management can accelerate overall project implementation, increase the potential for success, and yield greater benefits relative to projects not employing Adaptive Management.

Because our knowledge of ecosystems is often incomplete and project managers are faced with an array of uncertainties, project managers can rely on continuous assessment and data collection to guide modifications intended to optimize restoration projects. Data collection, comparison

with action criteria for performance standards, and risk endpoints are used to indicate the need for adjustments or modifications to the management actions. In order for Adaptive Management to work, there must be a clear mechanism for the monitoring results to be evaluated, a decision-making process, and an Adaptive Management Team identified to actively manage the overall iterative process.

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Ken Barr (Team Lead)	USACE, Rock Island District, CEMVR-PM-A
Tomma Barnes	USACE, Wilmington District, CESAW-TS-PF
Steve Bartell	E2 Consulting Engineers Inc.
Laura Brandt	US Fish and Wildlife Service, Lauderdale Research Center
Marci Johnson	USACE, Portland District, CENWP-PM-E
Barb Kleiss	USACE, LCA Science and Technology Director
Elmar Kurzbach	USACE, Jacksonville District, CESAJ-DR-R
Andy LoSchiavo	USACE, Jacksonville District, CESAJ-DR-R
Carol Parsons-Richards	Louisiana Office of Coastal Protection and Restoration
Greg Steyer	USGS, National Wetlands Research Center, Baton Rouge, LA
Richard Thomas	USACE, Great Lakes and Ohio River Division, CELRD-RBW
Bradley Thompson	USACE, Omaha District, CENWO-PM-AE

POINTS OF CONTACT: For additional information, contact the author, Dr. J. Craig Fischenich, (601-634-3449, *Craig.J.Fischenich@usace.army.mil*), or the manager of the Environmental Benefits Assessment Research Program, Glenn Rhett (601-634-3717, *Glenn.G.Rhett@usace.army.mil*). This technical note should be cited as follows:

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