Chapter 4
Science and Adaptive Management for a Changing Delta

Statute requires that the Delta Plan shall “Include a science-based, transparent, and formal adaptive management strategy for ongoing ecosystem restoration and water management decisions.” (Water Code 85308(f)). One definition of adaptive management is a flexible and learning-based approach to management where systems are managed to ensure improvements while an understanding of how these systems function is developed to raise the effectiveness of future management decisions and actions. Adaptive management is not currently being used to its fullest extent in the Delta, but the intent of this plan is to more effectively use adaptive management for planning, implementing, and decision making related to actions that affect Delta ecology, water operations and social networks.

The adaptive management approach provides a formal process that allows for making decisions on the basis of best available science, closely monitoring and evaluating outcomes, and reevaluating and adjusting decisions once more information is learned. Adaptive management is smart management – it provides the necessary flexibility and feedback to manage natural resources in the face of often considerable uncertainty about management effects. Adaptive management closely integrates policy, management and science in an ongoing, clearly structured, transparent, timely and inclusive cycle.

Adaptive Management and the Delta

The Delta and our understanding of the Delta are constantly undergoing change (e.g. Healey et al. 2008, Lund et al. 2010). Delta-related resource management decisions are often made without perfect information. Adaptive management is one approach that is appropriate for managing the Delta because adaptive management embraces uncertainty, monitors actions, evaluates outputs and outcomes, and revises policy decisions based on improved understanding (Christensen et al. 1996, Abal et al. 2005). Ideally, effective adaptive management for the Delta will derive from excellent science linked to governance that allows adjustments and changes to management decisions in a timely and transparent manner.

Delta plans, programs and projects should allow and plan for adaptive management of the Delta as a changing place. Adaptive management as defined in statute is, “a framework and flexible decision-making process for ongoing knowledge acquisition, monitoring, and evaluation leading to continuous improvements in management planning and implementation of a project to achieve specified objectives.” (Water Code §85052) Adaptive management is an approach to resource management applicable to systems that constantly undergo change because the approach is based on the science of learning by doing, embracing uncertainty, monitoring actions, evaluating outputs and outcomes, and revising policy decisions based on improved understanding (Christensen et al. 1996, Abal et al. 2005, Healey et al. 2008). This chapter presents the Delta Stewardship Council’s adaptive management framework. It is to be the policy of the Delta Stewardship Council that all Delta-related plans, programs and projects should clearly describe the appropriate use of adaptive management in planning, implementation and decision making. This chapter presents a framework for the application of adaptive management to proposed plans, programs, and projects. The review process and governance structure to support adaptive management are described in Chapter 10.

An Adaptive Management Framework

Several conceptual frameworks for adaptive management have been developed elsewhere and provide the basis for the adaptive management approach for the Delta Plan (Christensen et al. 1996, Stanford and Poole 1996, CALFED Bay-Delta Program 2000, Habron 2003, Abal et al. 2005, Healey 2008, Kaplan and Norton 2008, BDCP Independent Science Advisors on Adaptive Management 2009, Williams et al. 2009). While there are differences among various adaptive management conceptual frameworks, they generally contain three broad phases: plan, implement and decide. These three areas include nine logical steps.

- Planning is the first phase of the adaptive management conceptual framework. Planning includes the first five steps: 1) define/redefine the problem (findings); 2) establish goals, objectives, and performance measures; 3) model linkages between objectives and proposed action(s); 4) select action(s): research, pilot and full-scale; 5) design implementation action(s) with monitoring.
- Implementing is the phase that follows the planning steps of the adaptive management conceptual framework. Implementing includes three steps: 6) implement action(s) and monitoring; and 7) analyze, synthesize and evaluate; 8) communicate current understanding (this step spans the implement and decide phases of adaptive management).
- Deciding is the phase that follows the implementing steps of the adaptive management conceptual framework. Deciding largely refers to the step, 9) respond/adapt.

The Delta Stewardship Council will use the adaptive management framework in Figure 4-1 as a guideline for evaluating the use of adaptive management in Delta-related plans, programs, and projects. This framework and the description of each step are largely derived from Stanford and Poole (1996), Abal et al. (2005), CALFED Bay-Delta Program (2000) and the BDCP Independent Science Advisors on Adaptive Management (2009).

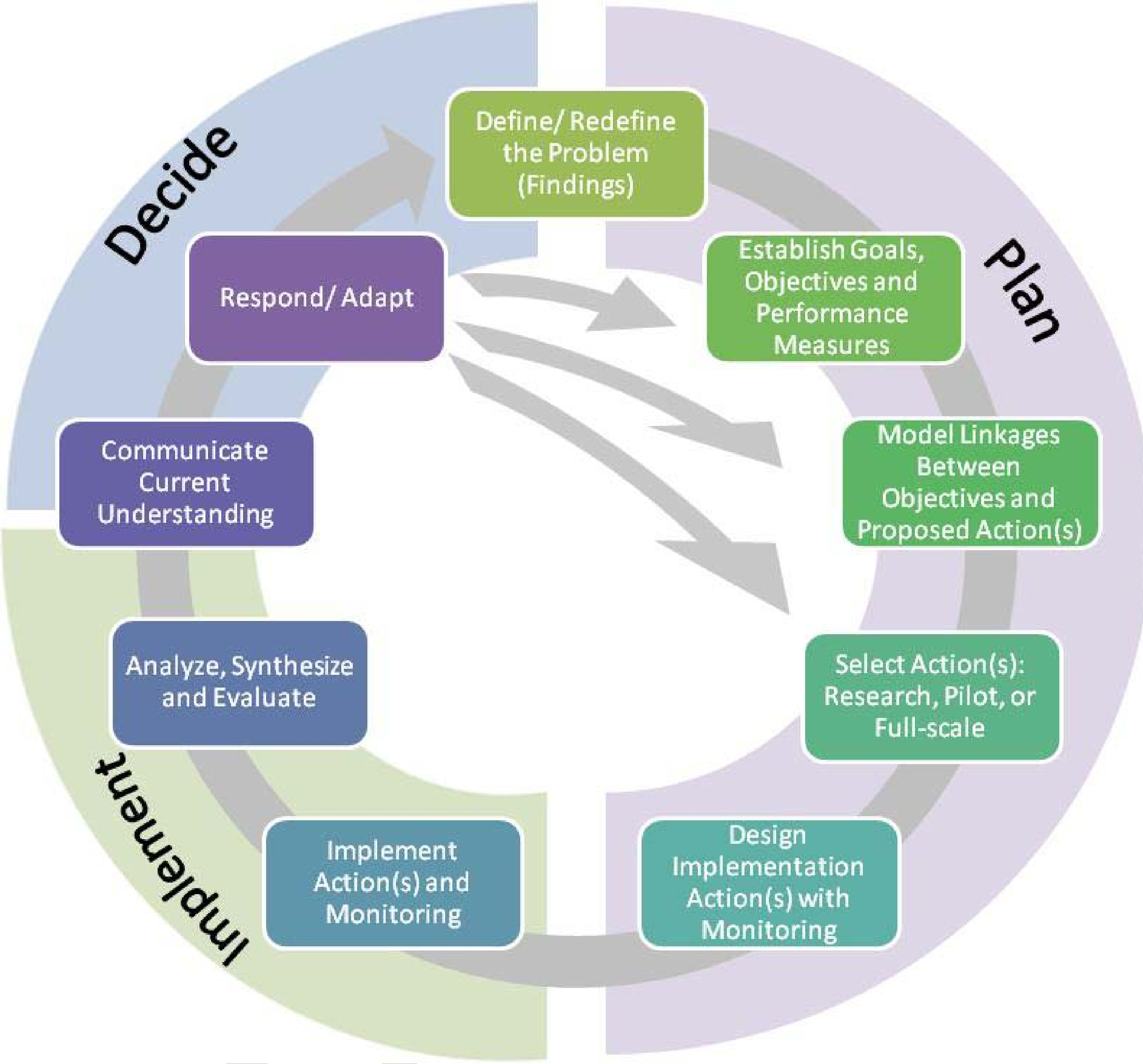

Figure 4-1. An adaptive management framework for the Delta Plan. The shading represents the three broad phases of adaptive management (Plan, Implement and Decide) and the boxes represent the steps within an adaptive management framework. The circular arrow represents the general sequence of steps. The additional arrows indicate possible next steps from the respond/adapt step.

1. Plan

The "plan" part of the adaptive management framework is presented as five steps.

Define/Redefine the Problem (Findings)

The first step of effective adaptive management is clearly defining the problem to be addressed. This may take the form of a finding or problem statement. The finding or problem statement should link clearly to program goals that are directly linked to specific objectives. Clearly stated problem statements should be stated by plan or project proponents in a transparent manner. All problem statements should be based on the best available, clearly documented information. Defining a problem commonly requires defining the boundaries of the problem (e.g. the geographic scale, temporal scale, and ecological processes). The defining or redefining (when justified by new understanding) of a problem requires those evaluating projects and plans to communicate directly and synthetically with senior decision makers (e.g. policy makers and program managers).

Establish Goals, Objectives, and Performance Measures

Clear goals, objectives, and performance measures must be established by senior decision makers who are familiar with and understand the relevant best available science. Goals are broad statements that propose general solutions. Objectives are more specific than goals, are often quantitative, and are specific statements of outcomes that reflect goals. Objectives should be tangible and measurable by performance measures so that progress toward achieving the objectives can be clearly evaluated. A performance measure is qualitative or quantitative information that tracks progress in meeting objectives and derives from a strong monitoring design.

Model Linkages between Objectives and Proposed Action(s)

Models formalize and apply current scientific understanding, develop expectations, assess the likelihood of success, and identify tradeoffs associated with different management actions. Models can be conceptual, statistical, or physical. Models link the objectives to the proposed actions in order to clarify why the intended action is expected to result in meeting its objectives. Both qualitative (conceptual) and quantitative models can effectively link objectives and proposed actions by illuminating if and how different actions meet specific objectives. Conceptual models in particular are very useful for both decision makers, scientists and the public because they provide a mental illustration about the most critical cause-and-effect pathways, providing an articulation of how various actions might achieve particular objectives. Conceptual models should be used within adaptive management planning because they help explain how other types of models, research and actions will be used to explore hypotheses and address specific uncertainties.

Select & Evaluate Action(s): Research, Pilot, Full-scale

The process for selecting and evaluating an action or suite of actions to meet objectives and performance measures includes an evaluation of the best available science and the developed conceptual model. This evaluation should inform the level of the action(s) to be taken (e.g. further research, pilot-scale project or full-scale projects), the physical and temporal scale of the action(s), the degree of confidence in its benefits, and the consequences of being wrong. This step should be performed by technical staff, such as scientists, engineers, land and water managers, and other project participants.

Design Implementation Action(s) with Monitoring

The design of implementation action(s) with associated monitoring includes clearly describing specific activities that will occur under that action(s). Design implementation includes a plan for both implementation of the actions(s) and monitoring responses from the action(s). This design step includes identifying adequate funding to carry out both the action(s) and the associated monitoring for the appropriate implementation period. Well designed data management should also occur in this step as data management is critical for analyses, synthesis and evaluations. Well designed data management also should include a plan for organized and clearly documented observations regarding how data is collected, the methods and calculations used, the time and space scales of the variables, and accurate site locations and characteristics.

The design of monitoring goes beyond data collection and data management. Monitoring includes targeted research to answer why certain results are observed and others are not. Monitoring also includes clear communication of the information gathered and current understanding drawn from this information. This monitoring includes compliance monitoring (e.g. required by permits), performance monitoring (e.g. measuring achievement of targets), mechanistic monitoring (e.g. testing the understanding of linkages in the conceptual model), and system-level monitoring (e.g. holistic and long-term). These types of monitoring can measure and communicate various types of information; for example, administrative/inputs (e.g. dollars awarded and spent, projects funded, etc.), compliance/outputs (e.g. tons of gravel added, acres exposed to tidal action, etc.) and effectiveness/outcomes (e.g. actual outcome expected from implementing an action at the local scale, suites of actions at the system-wide scales and status and trends assessments). Within the monitoring design, an integrated suite of monitoring metrics must be developed that can be integrated and summarized to inform decision makers and the public as described in the Communicate Current Understanding step.

2. Implement

The "implement" portion of adaptive management includes three steps.

Implement Action(s) and Monitoring

Implementation of actions and monitoring programs should occur in parallel. However, before an action is implemented initial conditions should be clearly documented so that a baseline is established. The implementation of action(s) and monitoring should be executed in a transparent manner and clearly communicated to the public. Status and trends metrics after implementation compared to these same measures in areas where implemented actions have not occurred are often good assessment tools.

Analyze, Synthesize and Evaluate

Analysis, synthesis, and evaluation of the action(s) and monitoring are critical for improving current understanding. Analysis and synthesis should be informative of how conditions have changed, both expected and unexpected, as a result of the implementation of the action(s). The evaluation should examine whether or not one or more of the performance measures have been met as a result of the implemented action(s) and why. If a performance measure is not met, an explanation of the potential reasons why this measurement has not been met should be clearly identified and communicated. The results of the analysis, synthesis, and evaluation step could be published in technical, peer-reviewed reports for the purpose of external review, transparency and accessibility where results warrant this level of communication.

Communicate Current Understanding

Communication of current understanding gained through analysis, synthesis, and evaluation of implemented action(s) and monitoring is a key step for educating and equipping policy makers, managers, stakeholders, and the public to appropriately respond and adapt. This step spans both the "implement" and the "decide" areas of adaptive management because the communication of current understanding and related recommendations for change requires both policy and technical expertise. The information communicated should be technically sound, well synthesized and translated into formats conducive to informing a non-technical audience (e.g. a report card) and should be disseminated to those directly involved in the adaptive management process for the plan, program or project and to those interested in the outcome of the action.

Technical staff and decision makers should be regularly involved in the exchange of information as data are analyzed and synthesized. Communication should be ongoing and occur at appropriate time scales for which an improved understanding could lead to refining other steps of the adaptive management framework. Key to successful communication is a skilled and dedicated interdisciplinary person or team that understands the technical information learned and the functional needs of the decision makers.

3. Decide

The “decide” area of adaptive management includes one key step, the respond/adapt step.

Respond/ Adapt

Senior decision makers need to be engaged and prepared to respond and adapt to a change in current understanding. Educated and equipped with new results and understanding, senior decision makers should reexamine the other steps of the adaptive management framework and adapt where current understanding suggests doing so. Possible next steps could include redefining the problem; amending goals, objectives, and performance measures; altering the conceptual model; or selecting an alternative action for design and implementation.

SUMMARY

The proposed Delta Stewardship Council’s adaptive management framework is intended to bring structure to decision making amidst uncertainties about the Delta’s environmental and social components and processes. The adaptive management framework can be applied at multiple levels (e.g. to plans, programs, and projects). The Council will use the adaptive management framework developed within the Delta Plan to make decisions amidst uncertainty for planning, implementation and decision making and for achieving the coequal goals. Flexible and responsive governance to support adaptive management is essential to successful application and is discussed in Chapter 10. The Council’s expectations for how other entities will apply the adaptive management framework for consistency with the Delta Plan and the Council’s adaptive management review process are also described in Chapter 10.

Box 1- Healthy Waterways Initiative in South East Queensland

- In South East Queensland, Australia, the Healthy Waterways Initiative was designed and implemented to improve the health of regional waterways and catchments including the ecosystems supporting the livelihoods and lifestyles of the people in this rapidly growing part of Australia. The initiative's collaborative partners developed an adaptive management framework as an operating philosophy for this partnership and the Healthy Waterways Plan. The adaptive management framework is cyclical and iterative with five major elements (Abal et al. 2005): Policy Planning, Implementation, Monitoring, Evaluation, and Improved Understanding. Adaptive management is a cornerstone of this decade-long omplemented intitiative to improve the waterways and bays in the region around Brisbane. Details about the Healthy Waterways Initiative and its adaptive management elements can be found at www.healthywaterways.org.

Knowledge Base for Adaptive Management

The knowledge base is the foundational scientific understanding of a system, both environmental and social, that creates the context for planning stages of scientific adaptive management. The following elements of the knowledge base are necessary to effectively plan, implement, and decide within an adaptive management framework: 1) best available science, 2) scientific research to understand change, and 3) monitoring to detect change. These elements create the capacity to make informed planning, meaningful implementation, and knowledgeable decision making.

Best Available Science

Best available science is specific to the decision be made and the time frame available for making that decision. There is no expectation of delaying decisions to wait improved scientific understanding. Action may be taken based on incomplete science if the information used is the best available at the time.

Best available science shall be developed and presented in a transparent manner including clear statements of assumptions, the use of conceptual models, description of methods used and presentation of summary conclusions. Sources of data used shall be cited and analytical tools used in analyses and syntheses identified. Best available science changes over time and decisions may need to be revisited as new scientific information becomes available. Targeted investment in science reduces scientific uncertainty and improves best available science.

Best available science must be consistent with the scientific process[1] which is described below and includes the steps for achieving best science, guidelines and criteria, effective communication and documentation, and a process for reviewing the scientific rationale upon which Delta Plan strategies and performance measures are built. Ultimately, best available science requires the best scientists using the best information and data to assist management and policy decisions. The processes and information used should be clearly documented and effectively communicated.

Steps for Achieving Best Science

Science consistent with the scientific process includes the following elements: well-stated objectives, a clear conceptual model, a good experimental design with standardized methods for data collection, statistical rigor and sound logic for analysis and interpretation, and clear documentation of methods, results, and conclusions. The best science is transparent; it clearly outlines assumptions and limitations. The best science is also reputable; it has undergone peer review conducted by active experts in the applicable field(s) of study. Scientific peer review addresses the validity of the methods used, the adequacy of the methods and study design in addressing study objectives, the adequacy of the interpretation of results, whether the conclusions are supported by the results, and whether the findings advance scientific knowledge.[2]

There are several sources of scientific information and trade-offs associated with each.[3] The primary sources of scientific information, in order of most to least scientific credibility for informing management decisions, include: Independently peer-reviewed publications including journal publications and books (most desirable); general reports and publications; science expert opinion; and anecdotal evidence, as summarized in Table 4-1. Each of these sources of scientific information may be the best available at a given time, containing varying levels of understanding and uncertainty. These limitations shall be clearly documented when used to inform decisions.

Table 4-1

Prioritized List of Sources of Science from Most to Least Scientific Credibility

Sources with more "scientific credibility" are at the top of the list.[4]

Source	Content	Review Level	Timeliness	Availability
Peer-reviewed publications	New findings	Formal, independent external	Slow to medium	Broadly available
General scientific reports and publications	Standard reports and analyses	Informal, internal/external	Medium	Available from source
Science expert opinion	Opinion and broadly held understanding	Through reputation only	Fast	Available from individuals and groups
Anecdotal evidence	Personal observations and beliefs	Limited to none	Fast	Available from individuals and groups

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[1] Sullivan, P. J., J. M. Acheson, P. L. Angermeier, T. Faast, J. Flemma, C. M. Jones, E. E. Knudsen, T. J. Minello, D. H. Secor, R. Wunderlich, and B. A. Zanetell. 2006. *Defining and implementing best available science for fisheries and environmental science, policy, and management*. American Fisheries Society, Bethesda, Maryland, and Estuarine Research Federation, Port Republic, Maryland. Available from http://www.fisheries.org/afs/docs/policy_science.pdf (accessed July 2010).

[2] Sullivan et al., 2006.

[3] Sullivan et al., 2006; Ryder, D.S., M. Tomlinson, B. Gawne, and G.E. Likens. 2010. *Defining and using 'best available science': a policy conundrum for the management of aquatic ecosystems.* Marine and Freshwater Research 61: 821-828.

[4] Adapted from Sullivan et al., 2006.

Guidelines and Criteria

Several efforts have been conducted in order to develop criteria for defining and assessing "best available science". In 2004, the National Research Council Committee on Defining the Best Scientific Information Available for Fisheries Management prepared a report (NRC Report) that concluded that guidelines and criteria need to be defined in order to apply best available science in natural resource management. [5] Major findings and recommendations included establishing procedural guidelines and implementation guidelines to govern the production and use of scientific information. The guidelines were based on six broad criteria which are (1) relevance, (2) inclusiveness, (3) objectivity, (4) transparency and openness, (5) timeliness, and (6) peer review.

The Legislature of the State of Washington also developed criteria for assessing best available science which are used by counties and cities in developing policies and regulations pursuant to the Washington State Growth Management Act. The State of Washington criteria include six characteristics for a valid scientific process: (1) peer review, (2) methods, (3) logical conclusions and reasonable inferences, (4) quantitative analyses, (5) context, and (6) references. [6]

For the purpose of informing adaptive management in Delta-related actions, plans, programs and projects, "best available science" for Delta-related activities should be consistent with the guidelines and criteria developed by the NRC and the State of Washington. Proposed, plans, program and projects should document that the science used follows the guidelines adapted from the NRC report as they apply to the Delta environment:

- **Relevance**. Scientific information used should be germane to the Delta ecosystem attribute and/or biologic organism (and/or process) affected by the proposed actions, projects, and programs. Analogous information from a different region, but applicable to the Delta ecosystem and/or biota may be the most relevant when Delta-specific scientific information is non-existent or insufficient. The quality and relevance of the data and information used shall be clearly addressed.

- **Inclusiveness.** Scientific information used shall incorporate a thorough review of all relevant information and analyses across all relevant disciplines. There are many analysis tools available to the scientific community. [7]

- **Objectivity.** Data collection and analyses considered shall meet the standards of the scientific method and be void of non-scientific influences and considerations. [8]

- **Transparency and Openness.** The sources and methods used for analyzing the science used shall be clearly identified. The opportunity for public comment on the use of science in proposed actions, projects, and programs is recommended. Limitations of research used shall be clearly

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[5] National Research Council, Committee on Defining the Best Scientific Information Available for Fisheries Management. 2004. *Improving the use of "Best Scientific Information Available" Standard in Fisheries Management.* National Academy Press, Washington D.C. Available from http://www.nap.edu/catalog.php?record_id=11045#toc (accessed July 2010).

[6] Washington Administrative Code (WAC) 365-195-900. Available from http://apps.leg.wa.gov/wac/default.aspx?cite=365-195-900 (accessed July 2010); Washington Administrative Code (WAC) 365-195-905. Available from http://apps.leg.wa.gov/wac/default.aspx?cite=365-195-905 (accessed July 2010).

[7] McGarvey, DJ. 2007. "Merging Precaution with Sound Science under the Endangered Species Act." Bioscience 57: 65-70.

[8] NRC 2004; Sullivan et al., 2006.

identified and explained. If a range of certainty is associated with the data and information used, a mechanism for communicating uncertainty shall be employed. [9]

- **Timeliness.** There are two main elements of timeliness: (1) data collection shall occur in a manner sufficient for adequate analyses before a management decision is needed, and (2) scientific information used shall be applicable to current situations. Timeliness also means that results from scientific studies and monitoring may be brought forward before the study is complete to address management needs. [10] In these instances, it is necessary that the uncertainties, limitations, and risks associated with preliminary results are clearly documented.

- **Peer Review.** The quality of the science used will be measured by the extent and quality of the review process. Independent external scientific review of the science is most important because it ensures scientific objectivity and validity. [11] The following criteria represent a desirable peer review process: [12]

    - Independent External Reviewers**.** A qualified independent external reviewer embodies the following qualities: (1) has no conflict of interest with the outcome of the decision being made, (2) can perform the review free of persuasion by others, (3) has demonstrable competence in the subject as evidenced by formal training or experience, (4) is willing to utilize his or her scientific expertise to reach objective conclusions that may be incongruent with his or her personal biases, and (5) is willing to identify all costs and benefits of ecological and social alternative decisions.

    - When to Conduct Peer Review**.** Independent scientific peer review shall be applied informally or formally to proposed projects and initial draft plans, formally to written review once official draft plans or policies are released to the public, and formally to final released plans.

    - Coordination of Peer Review**.** Independent peer review shall be coordinated by entities and/or individuals that (1) are not a member of the independent scientific review team, (2) have a particular and special expertise in the subject under review, and (3) have had no direct involvement in the particular actions under review.

Scientific Research to Understand Change

Scientific understanding about the Delta is not static and has changed considerably over time (Healey et al. 2008, Lund et al. 2010). For example, our understanding of key drivers in ecological and social components of the Delta has changed over time (See Box 2).

[9] Lukey, J.R., S.S. Crawford, and D. Gillis. 2009. "Effect of Information Availability on Assessment and Designation of Species at Risk". *Conservation Biology.*

[10] NRC, 2004.

[11] Meffe, G.K., P.R. Boersma, D.D. Murphy, B.R. Noon, H.R. Pulliam, M.E. Soule, and D.M. Waller. 1998. "Independent Scientific Review in Natural Resource Management." *Conservation Biology*. 12: 268-270.

[12] Adapted from Meffe et al., 1998.

In order to build the knowledge base for informing adaptive management within the Delta over the next few decades, ongoing investment in research is essential for understanding how the system changes over time. Delta related research should 1) focus upon key uncertainties, 2) support the best and brightest through competitive grant programs, 3) invest in young scientists and researchers, 4) utilize peer review in the selection of research projects, 5) look to local and outside experts to focus and define research topics, and 6) welcome and support alternative ways of learning about the system (e.g. through involvement of local communities in scientific projects and discussions). The Delta Science Program will be the central entity in supporting this research to understand the Delta as a changing place and build upon the knowledge base used to support adaptive management.

Box 2 - Examples of Changes in the Knowledge Base for the Delta

- *The State of Bay-Delta Science, 2008* was published to summarize and synthesize the current scientific understanding of the Bay-Delta at that time. The Delta Science Program, along with the Department of Fish and Game's [Ecosystem] Restoration Program, fund research to improve scientific understanding of the Bay-Delta ecosystem on topics relevant to decision-makers' needs for making informed management and policy decisions. http://www.science.calwater.ca.gov/pdf/publications/sbds/sbds_final_update_122408.pdf

- *Interagency Ecological Program 2010 Pelagic Organism Decline Synthesis of Results Through August 2010:* The 2010 IEP POD Synthesis report explains the evolution of the IEP's understanding of the POD and the Delta ecosystem over time. The 2010 report highlights the evolution of the POD conceptual model from 2005 to the present. The evolution of the conceptual model highlights the change in thinking from a classical food web and fisheries ecology approach, to species-specific models, to an ecological regime shift model. This evolution in thinking has come from monitoring and analysis of the Delta ecosystem over time. http://www.water.ca.gov/iep/docs/FinalPOD2010Workplan12610.pdf

Monitoring to Detect Change

Monitoring to detect change in the Delta will require that objectives of the monitoring are clearly linked to actions emanating from well-stated goals and objectives. Monitoring activities in the Delta should build upon the strengths and long-term data sets of the Interagency Ecological Program and other regional monitoring programs. The Interagency Ecological Program (IEP) is a collaborative effort among nine state and federal agencies to monitor ecological changes in the Delta (www.water.ca.gov/iep). This cooperative program produces publicly accessible data sets that include fish and wildlife status and trends, water quality, estuarine hydrodynamics, and food web monitoring.

Flexible Governance

Governance to support and implement adaptive management for a changing Delta must be flexible and responsive. Governance for adaptive management should be equipped to provide vehicles for facile decision making including a decision-making structure that fosters communication between scientists and decision makers, and has clear lines of authority where timely decisions are made and implemented. Governance for implementing adaptive management must provide for the institutional capacity to interact, learn, and adapt. Governance, oversight and review for the use of the adaptive management framework and supporting knowledge base presented in this chapter are explained in further detail in Chapter 10.

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