San Francisco Estuary
Wetlands Regional Monitoring Program Plan: Version 1 Framework and Protocols

Wetlands Regional Monitoring Program Steering Committee

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Wetlands Regional Monitoring Program Plan

Executive Summary

Mission Statement

The mission of the Wetlands Regional Monitoring Program (WRMP) is to provide the scientific understanding necessary to protect, create, restore, and enhance wetlands of the San Francisco Bay Region, through objective and cost-effective monitoring, research, and communication.

Geographic Scope

The geographic scope of the WRMP is the entire San Francisco Estuary plus the watersheds that drain to the Estuary within the nine-county San Francisco Bay Area. The WRMP will initially focus on the tidal baylands of the Estuary. The baylands consist of the mudflats, tidal marshes, diked historical tidal marshes, and other lands that would be tidal in the absence of existing levees, sea walls, tide gates, and other water control structures. The tidal baylands consist of the mudflats and tidal marshes.

Why the WRMP Is Needed

Wetland managers and the concerned public in the Bay Area have a long history in wetland conservation and protection. Their interest is expressed in many questions about the overall status and trends in wetland health and about the location and performance of wetland restoration and mitigation projects.

These questions cannot be answered at this time because the ambient condition of wetlands is not regularly assessed, the restoration and mitigation projects are monitored in disparate ways, there is little assurance of data quality, and the results are not readily available. Simply stated, there is no public measure of the environmental costs or benefits of most wetland management actions.

The WRMP was formed to define the basic information needs for managing wetlands, to develop a scientific framework with standard methods for monitoring wetlands and for interpreting the results, and to regularly report the findings to the public.

History of the WRMP

A plan for the WRMP was prepared by the San Francisco Estuary Institute for the USEPA in 1995. That plan called for the Wetlands Habitat Goals Project as the first step toward the WRMP. In 1999 and 2000, after the habitat goals were established, a multi-agency Steering Committee and core group of scientific Focus Teams were formed to continue working on the WRMP. During 2000 and 2001, additional Focus Teams were formed, existing monitoring methods were reviewed, management questions were compiled and prioritized, and a scientific framework was drafted. Also during 2001, the Focus Teams selected indicators and drafted protocols for data collection. Additional funding was received, and the framework was finalized. In 2002, the highest priority protocols were completed and compiled with the science framework to produce this version 1 WRMP Plan.

Science Framework

The science framework consists of conceptual models of tidal marsh form and function that help guide the monitoring design. The models are briefly summarized below.

- Estuaries exist between marine and riverine systems. Their defining feature is a salinity gradient from saline to freshwater conditions. The San Francisco Estuary extends between the Gulf of the Farallones and the inland Delta, but there are secondary gradients along each tributary river and stream. These secondary estuaries significantly influence the overall ecology of the San Francisco Estuary.

- The intertidal zone of the Estuary is transitional between the rest of the Estuary and the surrounding uplands. Environmental conditions vary from mostly estuarine to mostly terrestrial along the elevation gradient from the bottom to the top of the intertidal zone.

- The intertidal zone consists of tidal flats and tidal marshes. Tidal flats exist between zero tide height and the marsh foreshore. The marshes exist between the tidal flats and the uplands. Tidal flats and marshes consist of broad planes between channels large and small that form dendritic drainage networks. Channel banks in tidal marshes are long extensions of the foreshore. The shoreline is fractal in plan view; shorter yardsticks yield longer measurements of total shoreline length.

- The creation and natural maintenance of tidal wetlands depend on regular supplies of water and sediment, the former to submerge the land, and the latter to prevent the land from being too deeply submerged.

- In general, climate, geology, and land use control supplies of water and sediment, which in turn control vegetation, which in turn affects the distribution and abundance of animals. Land use strongly influences the status and trends of intertidal ecosystems.

- The geomorphology of the intertidal zone creates a dynamic template for bio-geo-chemical and ecological processes, as mediated by vegetation. Physical factors and communities of plants and animals vary predictably along the estuarine gradient between marshes, along the elevation gradients within marshes, and along the gradients of environmental stress created by land use.

- Successful adaptive management of the intertidal zone requires regular inputs of empirical data for indicators of environmental response to management actions.

WRMP Management Structure

The WRMP is designed as the monitoring organization of the San Francisco Bay Area Wetlands Restoration Program. The proposed management structure of the WRMP calls for a Steering Committee and Science Review Group to provide policy and science oversight. The daily operations of the WRMP would be managed by a Science Coordinator, Program Manager, Administrative Assistant, and Data Managers. The WRMP would contract with scientific Focus Teams for data collection and analysis. The Focus Teams, Science Coordinator, Program Manager, and Science Review Group would share responsibility for interpretation and reporting of technical findings, subject to independent peer review. The Regional Monitoring Program for Trace Substances is the model for this management structure.

Technical Components and Products

The WRMP will include four major technical components: ambient monitoring, project monitoring, special studies, and an information system.

- A 3-tiered approach to ambient monitoring will (1) track the overall distribution and abundance of wetlands; (2) assess the status and trends in wetland condition using rapid assessment of random samples of wetland sites; and (3) intensive monitoring of reference sites along stressor gradients to calibrate the rapid assessment methods.

- There will be a common set of indicators for monitoring ambient conditions and for monitoring the condition of wetland projects, such that projects can be compared one to another and over time, and so that projects can be assessed in the context of ambient variability. Project monitoring through the WRMP will also involve the review of site-specific monitoring plans and results.

- Special studies will be carefully focused to improve the interpretation of monitoring results.

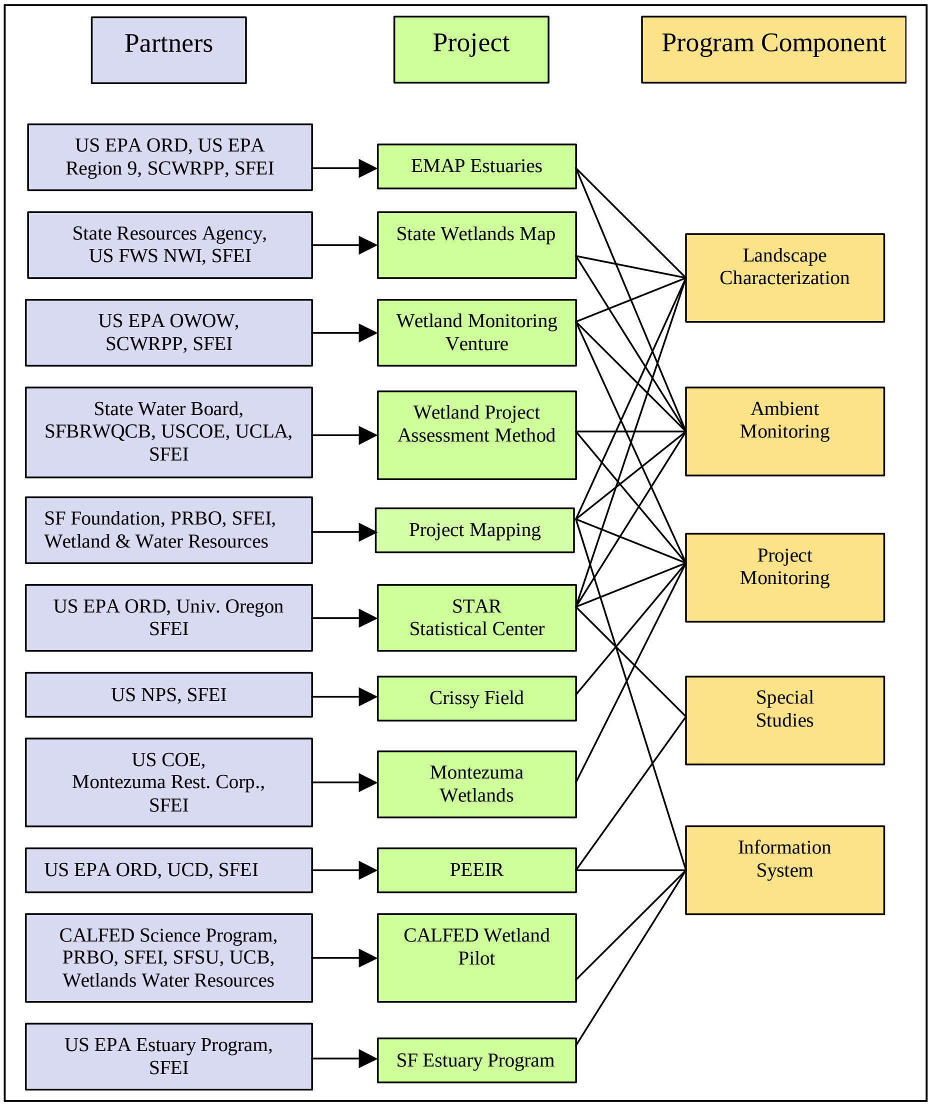
- An information system is being developed for data sharing among WRMP collaborators, and for public access to qualified data sets and finalized reports.

What to Measure

The Focus Teams have nominated indicators for intensive ambient monitoring and for project monitoring. These indicators relate directly to the management questions and are consistent with the science framework. Data collection protocols have been prepared for some of the most basic candidate indicators: habitat distribution and abundance, tidal elevation, sedimentation, contamination, plant community structure, status of protected species, and avian support. Additional protocols will be developed in the future.

Program Status

Funded projects for FY 2002-03 are being coordinated to implement each component of the WRMP. Total funds to WRMP members through these projects this year total more than $1,000,000 not including in-kind services.



Funding Strategies

There are a variety of possible ways to fund the WRMP. A combination of approaches might be required. A likely strategy would involve contributions of monitoring fees paid by project sponsors in lieu of other monitoring requirements, annual contributions by WRMP member agencies, and competitive grants from agencies and foundations. Large endowments would provide the most secure funding over the long-term. The criteria for choosing a strategy should include safekeeping of the neutrality of the WRMP. The WRMP should have no financial or political interest in the monitoring results.

San Francisco Estuary Wetlands Regional Monitoring Program Plan

Part 1: Framework

Mission Statement

The mission of the Wetlands Regional Monitoring Program (WRMP) is to provide the scientific understanding necessary to protect, create, restore, and enhance wetlands of the San Francisco Bay Region, through objective and cost-effective monitoring, research, and communication.

Geographic Scope

The geographic scope of the WRMP is the entire San Francisco Estuary plus the watersheds that drain to the Estuary within the nine-county San Francisco Bay Area.

The WRMP will initially focus on the tidal baylands of the Estuary. The baylands consist of the mudflats, tidal marshes, diked historical tidal marshes, and other lands that would be tidal in the absence of existing levees, sea walls, tide gates, and other water control structures. The tidal baylands consist of the mudflats and tidal marshes.

By starting with the tidal baylands, the WRMP is taking a logical next step in regional monitoring that has begun in the estuarine straits and bays and should eventually extend through the baylands into watersheds. The tidal baylands are transitional environments between local watersheds and bays. They link bays and watersheds together. They can therefore serve as the venue for coordinating different scientific programs that focus on watersheds, rivers and streams, or aquatic habitats of the Estuary.

The geographic scope of the program should be broadened in the future to include all the different kinds of wetlands in the region. The WRMP should be coordinated with other monitoring programs for comprehensive and consistent monitoring of wetlands throughout the San Francisco Estuary and all of its watersheds.

Statement of Need

Large amounts of public funds and human resources are being invested in the creation, restoration, and enhancement of wetlands in the region. Major initiatives call for the restoration of many tens of thousands of acres of wetlands during the next few decades. These restoration projects are expected to improve the existing wetland ecosystem that is already highly valued. The size of wetland projects is increasing. The costs and potential effects of the projects are therefore also increasing.

A comprehensive monitoring program is needed to evaluate the effects of wetland policies, programs, and projects in the Estuary and its watersheds. Wetlands need to be compared to each other and over time to assess the status and trends of the wetlands ecosystem, measure the progress and effects of wetland projects, assess the efficacy of management actions, and otherwise account for the public investment in wetlands.

The information needs of wetlands managers cannot be met at this time because the ambient conditions of wetlands are not being monitored, the wetlands restoration and mitigation projects are monitored in disparate ways, there is little assurance of data quality, and monitoring results are not readily available. Simply stated, there is no accounting of the environmental costs and benefits of most wetland management actions.

Program Origins

Federal and California State agencies have formally recognized the need for a regional wetlands monitoring program. In 1993, the Governor of California and the Administrator of the US Environmental Protection Agency (USEPA) signed the Comprehensive Conservation and Management Plan (CCMP) for the San Francisco Estuary as part of the National Estuary Program of the federal Clean Water Act. At about the same time, the Governor issued the California State Wetlands Conservation Policy. The CCMP and the Governor's policy on wetlands both call for a wetlands conservation plan for the Bay Area based upon habitat goals, and a comprehensive regional monitoring program. The CCMP also calls for the creation of the San Francisco Estuary Institute (SFEI) to help coordinate the monitoring efforts.

The Bay Area Wetlands Ecosystem Goals Project was an important early step toward the WRMP. From autumn 1994 to spring 1999, a broad coalition of federal, state, and local agencies worked with non-governmental science organizations, universities, and private environmental consultants to produce a set of maps showing the proportions and relative positions of wetland habitats needed in the region to assure the health of the regional wetlands ecosystem (Goals Project 1999). Science support for the Goals Project was coordinated by SFEI, as called for by the CCMP. The Goals Project established working relationships among many wetland interests in the region, and it created a quantitative regional basis for monitoring the performance of local wetlands projects.

In autumn 1999, after the regional goals were set, many of the agencies that had been involved in the Goals Project came back together with SFEI to begin developing the WRMP Plan. The USEPA and the California Coastal Conservancy agreed to serve as co-chairs of a multi-agency Steering Committee, and SFEI agreed to coordinate science support. Leading scientists and engineers in the region were appointed to the Steering Committee and asked to form scientific Focus Teams for broad, multi-disciplinary advice and review. During the past two years, the Steering Committee and its Focus Teams have worked with SFEI to produce this first public version of the WRMP Plan. The Steering Committee expects that new versions of the Plan will be produced as needed to accommodate changes in monitoring objectives and increased technical understanding about wetlands.

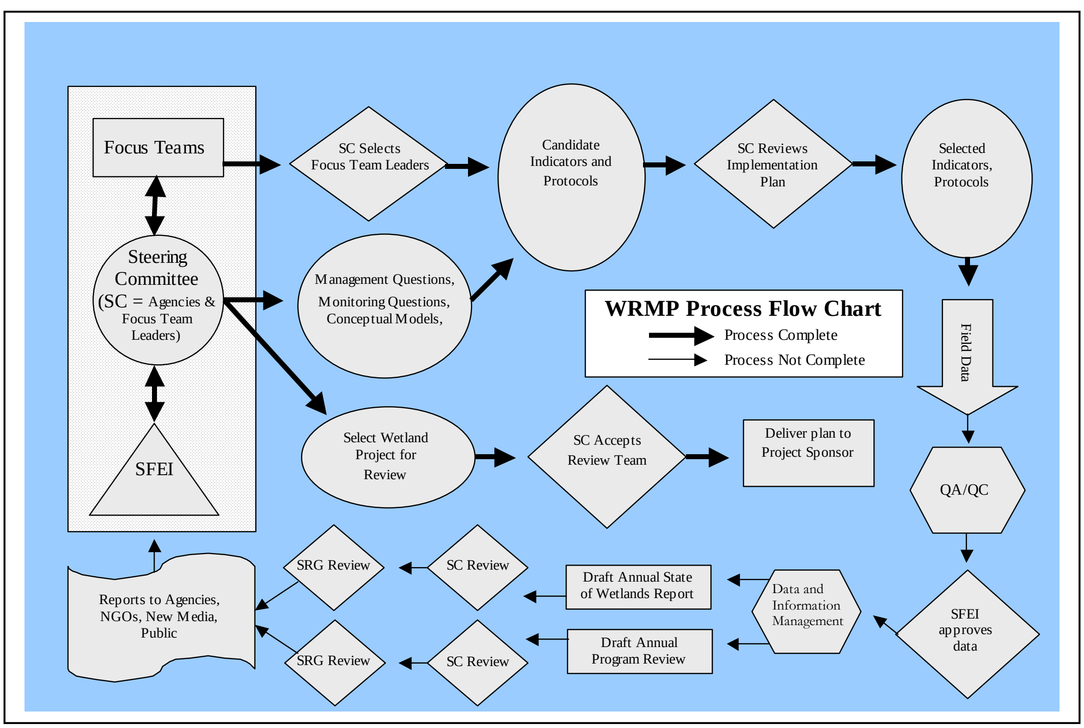
Program Development

The WRMP was initiated with the formation of a Steering Committee and its scientific Focus Teams for Physical Processes, Contaminants (Bio-Geo Chemistry), Invertebrates, Plants, Fish, Amphibians-Reptiles-Mammals, and Birds. A Team for Landscape Ecology was added after the other Teams were formed. These Teams were called for by the Steering Committee to help develop a plan to assess the status and trends of tidal marshes in the region and to assess the progress of wetland projects.

Soon after the Steering Committee was created, it began to formulate a plan for program development. The WRMP has progressed with the identification of important management questions and conceptual modeling of wetlands form, processes, and functions. Indicators have been nominated based upon these questions and models. Standard protocols for data collection for the key indicators have been prepared by the Focus Teams. At the same time, wetland projects are being selected for review by the WRMP with regard to the adequacy and meaning of their monitoring data. In short, there has been significant progress in the development of both the ambient monitoring and the project monitoring components of the Program.

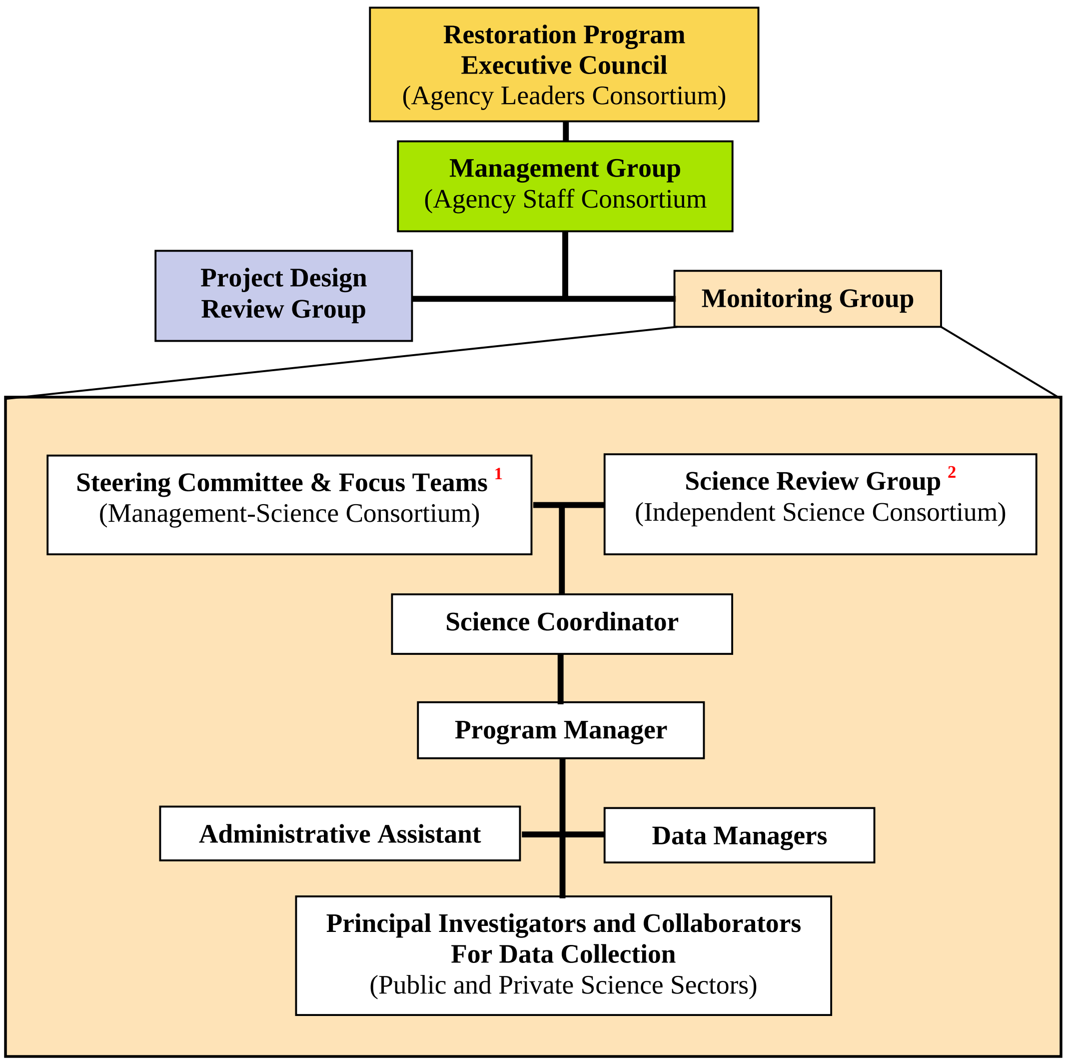
The Steering Committee correctly anticipated that funding for data collection and information system development would begin in 2002. A plan of transition from planning of the WRMP to its implementation has been produced.

The formation of the Bay Area Wetlands Restoration Program was also anticipated by the Steering Committee. The WRMP has begun to transition from being a multi-agency initiative to being a major component of the Restoration Program



Management Structure, Staffing Plan and Basic Work Flow

The WRMP is designed as the monitoring organization of the San Francisco Bay Area Wetlands Restoration Program. A committee of state and federal agency executives who have the authority to coordinate policy planning and to direct the human and financial resources of their agencies governs the Restoration Program. The Executive Committee is supported by a Management Group of senior staff from the agencies who can summarize issues for the Executive Committee. The Management Group oversees the work of the Design Review Group and the WRMP. The Design Review Group provides technical advice and review for wetland restoration and mitigation projects, and works closely with the WRMP to identify the priorities for project monitoring.



1. The Management Group of the Restoration Program might subsume the duties of the Steering Committee.
2. The Science Review Group could be elevated to the Restoration Program at the same tier as the Management Group.

The proposed management structure calls for continuation of the Steering Committee, Focus Teams, Science Review Group, Science Coordinator who prepared this Program Plan. The proposed structure also calls for Program Manager, Administrative Assistant, and Data Managers who are employed to run the day-to-day operations of the WRMP, and Principal Investigators and Collaborators who are funded as sub-contractors for data collection and analysis under the direction of the Science Coordinator and Program Manager.

The WRMP must be carefully structured with adequate administrative and scientific support to achieve the coordination and collaboration of a successful Program. A structure has been designed to meet the following general requirements, based on the initial projects of the WRMP during FY 2001-03.

- The structure must include administrative support for timely and accurate accounting and reporting of workflow and finances. The Program cannot succeed without adequate resources dedicated to program administration, including contracting and personnel management.

- The structure must support the goals and objectives of the Program, with an emphasis on scientific excellence. The program should be able to assemble the best scientific teams possible from all available resources, private or public. The Program should be open to new ideas and talent, but should provide continuity through stable institutions and professional mentoring.

- The structure must promote integration among the many scientific disciplines of the Program. The structure should facilitate open interpretations of monitoring and research results from a variety of scientific perspectives.

- The structure must include pathways of information flow between wetland scientists and wetland managers to assure that the Program has the feedback mechanisms necessary to practice adaptive management.

Steering Committee

The Steering Committee consists of senior staff in the wetlands regulatory, management, and protection agencies of the region plus the Leaders of the scientific Focus Teams. A core group of agency members, including the co-chairs, initially decides the number of Focus Teams and nominates Team Leaders. The selected Team Leaders can help adjust the role of the Steering Committee and the Focus Teams. Membership in the Steering Committee is not necessarily restricted to any particular group of agencies or scientists. New members can be added to build institutional support and relevance for the Program. Some governmental members of the Steering Committee also serve of the Management Group of the Restoration Program.

The Steering Committee has been responsible for translating management questions and concerns into monitoring questions and special study objectives. The Steering Committee has also responsible for overall Program planning and development, including selection of Focus Team Leaders, formulation of Focus Team tasks, oversight of special studies, direction of the Science Coordinator and support staff, plus development of this Program Plan.

The Steering Committee has played an essential role to govern the WRMP during its early development in advance of the establishment of the Recovery Program. The Steering Committee has also served as the intersection of science and management. In the future, the duties of the Steering Committee of the WRMP may be subsumed by the Management Group of the Recovery Program, which may interact directly with the Focus Team Leaders and with the Science Coordinator to sustain the dialogue between managers and scientists.

WRMP Steering Committee
Active Member Organizations 2002

US Army Corps of Engineers

California State Resources Agency

US Environmental Protection Agency

SF Bay Regional Water Quality Control Board

US Fish and Wildlife Service

California Department of Fish and Game

National Oceanic and Atmospheric Administration

California Coastal Conservancy

SF Bay Joint Venture

SF Bay Conservation and Development Commission

San Francisco Estuary Institute

San Francisco State University

University of California at Berkeley

Napa County Mosquito Abatement District

Contra Costa County Mosquito Abatement District

Point Reyes Bird Observatory

Scientific Focus Teams

The Focus Team Leaders form their Teams based upon criteria developed by the entire Steering Committee. The Team Leaders serve as liaisons between the Steering Committee and the Focus Teams. The Teams provide ongoing technical support to the WRMP. For example, since their inception in spring 2000, the Focus Teams have been building the scientific foundation of the Program. They have been developing conceptual models of wetlands form and function; translating management questions into monitoring questions; nominating indicators of wetlands status, trends, processes, and functions based on the conceptual models and management questions; drafting protocols for data collection; and describing broad approaches to sampling and data analysis.

The next stage of Program development will require the Focus Teams to transition from planning to implementation. Focus Team members are likely to be involved with data collection through their own organizations. To the extent that the WRMP receives grants and contracts to conduct monitoring, the Focus Team Leaders will serve as Principal Investigators. The main continuing role of the Focus Teams in the WRMP will be for protocol development and review of monitoring results and Program reports. The Focus Teams will continue to work through the Team Leaders as the Program Plan is implemented.

Focus Teams and Leaders for WRMP 2001-02

Physical Processes Team	
Karl Malamud Roam	Contra Costa Mosquito Abatement District
Stuart Siegel	Wetlands and Water Resources
Bio-Geo Chemistry Team	
Jay Davis	San Francisco Estuary Institute
Plant Team	
Mike Vasey	San Francisco State University
Invertebrates Team	
Bruce Thompson	San Francisco Estuary Institute
Fish Team	
Todd Hopkins	San Francisco State University
Mammals, Reptiles, and Amphibians Team	
Andree Breaux	Regional Water Quality Control Board
Birds Team	
Gary Page	Point Reyes Bird Observatory
Nadav Nur	Point Reyes Bird Observatory
Landscape Ecology Team	
Maggi Kelley	University of California at Berkeley
Statistical Design Team	
Don Stevens	Oregon State University

<u>Science Review Group</u>

The Science Review Group (SRG) has been planned but not established. It is expected to involve scientists and engineers, who do not serve on any Scientific Focus Team of the WRMP, do not expect to gain political or financial benefit from the outcomes of the WRMP, but who have outstanding abilities to advise and review regional science programs. SRG members can come from inside or outside the region.

To provide the level of technical advice and review that is required, the SRG might need to include experts in the larger scientific or technical aspects of the WRMP, including ecology, biology, hydrology, program-level statistical design, science management, and information technology. It is also anticipated that the SRG will include members who understand the tensions between environmental science and policy, such that they can help the Management Group and Executive Council fashion an effective monitoring program.

The Science Review Group may be elevated to the Recovery Program at the tier of the Management Group to more directly advise the Mangers Group and the Executive Council.

The Steering Committee has asked the Committee of Science Advisors (CSA) of SFEI to help develop a detailed duty statement for the SRG and to help recruit qualified members. The CSA has worked with the chairs of the Steering Committee to draft the following broad statements about the potential role the SRG.

Draft Description of Roles and Responsibilities for the Science Review Group Noting Key Questions to Answer

- Review the overall program plan, especially the relationship between program structure and program mission. Is the design of the Program consistent with the Program's?
- Review the structure of the program, especially with regard to integration across disciplines. Does the Program promote scientific integration?
- Review the quality controls and quality assurances for the monitoring data. Are data subject to excessive or undisclosed error or bias?
- Review the relevance or value of the monitoring questions. Are the right questions being asked?
- Help estimate the needed levels of funding and staffing to assure Program success. Is the Program over-reaching or not reaching far enough?
- Review the rationale for selected indicators, indicator sets, and indices. Are the right methods of data collection and analysis being used in the correct ways?
- Review the data management and information systems. Are data adequately protected and accessible for the right audiences?
- Help develop a process of scientific review and revision of the Program and the technical products. What should be the process of overall Program review? Are the products useful?

Science Coordinator

The Science Coordinator fosters overall technical support for the WRMP. Since the inception of the Program, the Science Coordinator has drafted scopes of technical work for the Focus Teams, developed guidelines to conduct the work, drafted development plans for the Program, written proposals for funding to support the science and information technology of the Program, planned and held conferences and discussion sessions to reach consensus about technical approaches, presented the Program to related interests inside the region and elsewhere, and transferred outside expertise to the WRMP.

In the future, the Science Coordinator will continue to play a lead role in coordination of technical efforts within the Program and between it and related science programs and projects. The Steering Committee of the WRMP (and/or the Management Group of the Recovery Program) can request the Science Coordinator to respond to service requests from the Focus Team Leaders, the Science Review Group, and other groups of the WRMP.

Draft Description of Roles and Responsibilities for the Science Coordinator

- Foster collaboration among the Focus Teams and data authors.
- Foster integration between the policy interests and science interests of the WRMP and other aspects of the Restoration Program.
- Foster technical collaboration between the WRMP, Design Review Group, and other technical organizations outside of the Restoration Program.
- Help develop strategies and proposals for funding science in the Restoration Program.
- Help inform other Program participants about technical studies and reports related to their interests.
- Develop and help conduct a peer review processes for the WRMP.
- Communicate Program and project plans, status, and findings to a broad range of different audiences.
- Represent the Restoration Program at regional, national, and international scientific conferences and symposia.
- Oversee the design and content of the annual public report of the Program.
- Oversee quality control and quality assurance procedures.

WRMP Program Manager

The Program Manager will be responsible for the daily operations of the Program, as directed by the Steering Committee of the WRMP and/or the Management Group of the Restoration Program. The WRMP Program Manager and the Science Coordinator will work closely together to make certain that the Coordinator can support the internal operations of the Program, and that the Manager can support the outreach efforts and coordination with other programs and projects.

This will include soliciting contractors and managing contracts, organizing fieldwork among al data collectors. , Planning and holding meetings and workshops, supervising QA/QC and data flow, organizing internal and external reviews, and reporting.

Draft Description of Roles and Responsibilities for the Program Manager

- Prepare requests for proposals, select contractors for data collection and analysis, and manage their contracts.
- Help the Science Coordinator manage a process of refereed peer review.
- Plan and hold technical meetings, workshops, and conferences.
- Work with the Steering Committee and/or Mangers Group to develop and distribute agendas, schedules, and minutes of WRMP meetings.
- Coordinate the Information Technology Team and Administrative Assistant with regard to the Program.
- Oversee the production of the annual public report of the Program.
- Provide supporting materials to the Steering Committee, Science Coordinator, Science Review Group, and Data Authors.

<u>Administrative Assistants</u>

The Administrative Assistant will provide clerical and administrative support to the Science Coordinator and the Program Manager, with an emphasis on contract management and personnel support. For example, the Administrative Assistant will direct outside requests for information, plan logistical and facilities support for meetings and conferences, maintain rosters and contact lists, handle bulk mailings, work with accountants to maintain current ledgers, help track project timelines for timely completion of progress reports and tasks, and prepare invoices.

<u>Information Technology Team</u>

The IT Team includes one or more database designers and managers, QA/QC officers, web masters, and report production personnel. The IT Team is responsible for technical development and maintenance of the information system, including databases; data formatting; implementing quality controls and quality assurances; web site development and maintenance; creation and maintenance of list servers and other electronic communication methodologies; GIS development and production; and the design, layout, and production of WRMP reports.

Data Authors and Collaborators

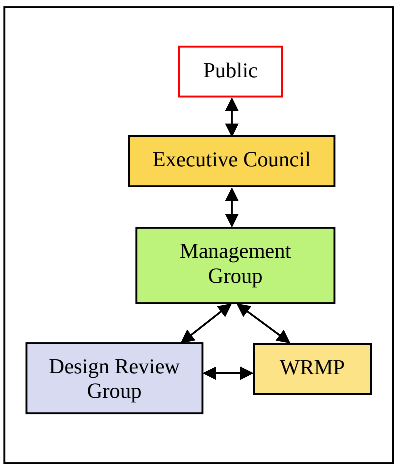
The Data Authors and Collaborators will be responsible for data collection, analysis, and data entry into the information system for the Program, as directed by Program Manager. Data authors will participate in original interpretations of the data, and they will review reports and other products that are based on their data. In some cases, Focus Team Leaders or members will be Data Authors or Collaborators. The Program Manager will work with the Steering Committee and/or Management Group to prevent conflicts of interests for partners and collaborators who participate in planning as well as implementation of the WRMP.

Work Flow Scenarios

Improving Wetland Projects

The following scenario describes the expected working relationships between the Executive Council, Management Group, Design Review Group, and the WRMP for improving the design and function of wetland restoration and mitigation projects.

Scenario 1: Project Monitoring



A. The Management Group and the Executive Council select a wetland project to be addressed through the Recovery Program. A project might be selected because it is especially important in ecological or economic terms and therefore might incur unusually large risks, or it might represent special opportunities to advance the science of wetland restoration or monitoring. Any person or organization can nominate a project to the Management Group for address through the Restoration Program.

B. The Management Group sends the selected project to the Design Review Group, which assembles the expertise necessary to describe, in qualitative terms, the technical uncertainties and ecological risks surrounding the project. The Design Review Group will also provide early advice on appropriate ecological goals and objectives for the project, given its location, size, existing ecological functions, and constraints, in the context of the Regional Habitat Goals and other concerns. Based on the project's goals and objectives, the Design Review Group and the project sponsor work together to render a set of habitat conceptual designs.

C. The Design Review group provides the goals, objectives, qualitative risk assessment, and conceptual habitat plans to the WRMP. The WRMP adds recommendations about which stressors and response indicators should be monitored for the project. The recommendations include instructions for standard data collection, data quality control, data management, and data review. The protocols for data collection have been readied by the WRMP with peer review. The Design Review Group and the WRMP provide a joint report of technical uncertainties and ecological risks, project goals, objectives, habitat plans, and monitoring recommendations to the Mangers Group.

D. The Management Group transfers the joint report on the project from the Design Review Group and the WRMP to the project sponsor.

E. The project sponsor develops the detailed engineering plans and monitoring plans for the project, and provides these to the Management Group, which transfers them to the Design Review Group and the WRMP for their review. The Design Review Group and WRMP meet jointly with the project sponsor to work out any critical revisions in the project design or the monitoring plan.

F. The project sponsor receives permits for the project, initiates the project on the ground, and begins monitoring the project.

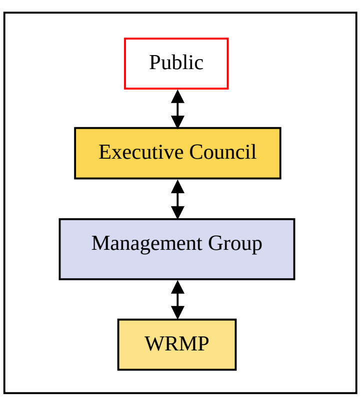
G. Based on the monitoring recommendations, the data come from the project sponsor to the WRMP for management. The project sponsor's analyses and interpretations of the monitoring data are reviewed by the WRMP, in conference with the Design Review Group and the project sponsor. The WRMP, Design Review Group, and project sponsor provide a joint report to the Management Group on the status and trends of the project, relative to ambient conditions. If necessary, majority and minority opinions are presented. The report may include recommendations for changes in habitat design, engineering, and monitoring.

H. The Management Group reports the status and trends for the project to the Executive Council, which authorizes a public report from the Management Group.

Monitoring Ambient Conditions, Stressors, and Ecosystem Functions

The following scenario describes the expected working relationships between the Executive Council, Management Group, and the WRMP for monitoring major stressors, ambient status and trends of wetlands in the region, and the ecosystem effects of wetlands projects.

Scenario 2: Ambient Monitoring And Special Studies



A. Each year, the Executive Council and the Management Group work with the WRMP to define the highest priority in formation needs (i.e., management questions) that should be addressed by the WRMP.

B. The WRMP translates the management concerns into monitoring questions or special study objectives. The WRMP provides the Management Group with a general technical approach and scientific rationale for addressing each priority question. The plan will include a description of inter-dependencies among the questions such that their priority rankings can be revised.

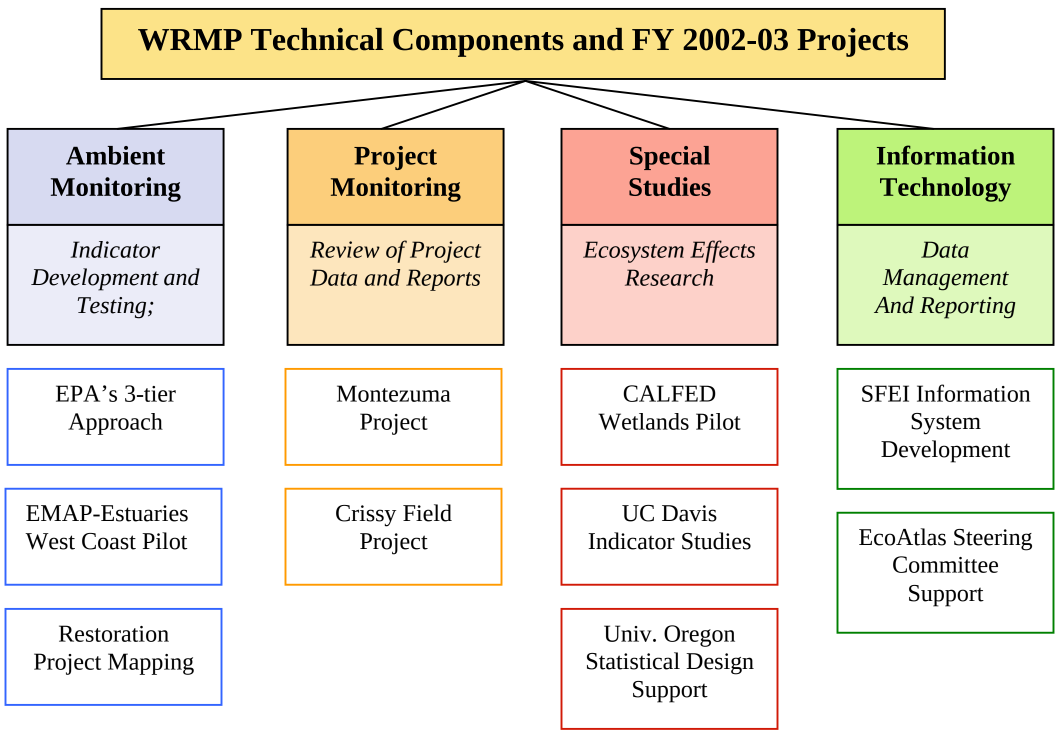
C. For ambient monitoring, the WRMP develops or revises the set of standard approaches for data collection, data management, data quality control, analysis, and reporting. For special studies, the WRMP collaborates with other programs and organizations to develop the study plan. This step can involve collaborations among many sources of expertise, plus peer review.

D. The WRMP arranges for data collection through agencies, NGOs, private contractors, and academic institutions.

E. The WRMP works with the data authors to prepare annual reports to the public through the Management Group and the Executive Council on the regional status and trends of wetlands.

Major Technical Components of the WRMP

The WRMP will eventually include four major technical components for the development and dissemination of original information about wetlands: ambient monitoring, project monitoring, special studies, and information technology. The chart below shows the anticipated WRMP projects for each of the four major components of the WRMP for FY 2002-2003. Most funding at this time is for program development. During FY 2003-04, ambient monitoring will shift in focus from indicator development to data collection, and Information Technology will shift from system development to reporting.



Ambient Monitoring

The ambient monitoring component is needed to (1) understand the prevailing conditions, processes, and functions of different types of wetlands and the large-scale or cumulative effects of wetland management actions, including the effects of restoration and mitigation projects; and (2) enable project sponsors and managers to assess the performance of wetlands projects relative to the variability among comparable wetlands. The ambient monitoring component will initially focus on tidal baylands.

Ambient monitoring will need to answer questions about wetlands at many scales of time and space, from local habitat patches and mosaics of patches within subregions to the regional wetlands ecosystem as a whole. The Steering Committee has compiled a list of management questions that should be answered through ambient monitoring. The list of management questions is provided as Appendix A (the criteria for selecting questions are presented on page 19 of this Plan).

A conceptual framework for ambient monitoring has been drafted to address the wetlands management questions. The framework can evolve over time, as experience is gained and new questions arise. The framework includes generalized conceptual models that represent the known and expected ecological, hydrological, and geomorphic functions of the major types of wetlands in the Region. The framework is presented as Appendix B (a summary of the framework is provided on pages 20-31 of this Plan).

The ambient monitoring program will have a tiered approach to data collection and wetland assessment. Tier 1 involves regional mapping and characterization of wetlands. Tier 2 involves a regional rapid assessment of randomly selected wetlands sites of each major kind. Rapid assessment involves brief surveys of each selected wetland by expert assessment teams. Tier 3 involves intensive monitoring to calibrate and validate rapid assessment methods along gradients of environmental stress. To the extent possible, ambient monitoring will involve standardized protocols for data collection and centralized data management.

The ambient monitoring component of the WRMP is intended to be a primary source of information needed to develop predictive models for the performance of wetland restoration projects and the evolution of the wetland ecosystem, as affected by natural processes and the actions of people. The results of the program should be used in an ongoing way to define and quantify the ecological risks and uncertainties of wetland management. The WRMP will help convey this understanding to the public in the form of annual reports on the status and trends of wetlands in the region.

Project Monitoring

The project-monitoring component of the WRMP is needed to assess the performance of local wetland projects relative to regional habitat goals and ambient variability. The project-monitoring component will initially focus on the performance of tidal marsh restoration and mitigation projects. There is no provision at this time for any project evaluation that is conducted by the Restoration Program to replace or influence the regulatory evaluation by the permitting agencies.

The Management Group of the Restoration Program envisions that the Design Review Group will provide advice and review of the habitat concepts and engineering designs of selected projects of special importance (see Step A of Operational Scenario 1 on p.10). After this initial review, project-specific goals and objectives are finalized, and indicators of performance and stress are selected. Standard protocols are used to collect data that are comparable to ambient monitoring data. The data that pass through quality control and assurance procedures are used by the project sponsors and the Management Group to evaluate project performance, relative to the regional habitat goals and project goals. If necessary, the project goals and objectives, the project designs, and the monitoring plan are adjusted to accommodate lessons learned. The evaluations are provided to the public and to the project sponsor.

It is anticipated that the project-monitoring component of the WRMP will be initiated with the review of monitoring data and reports for a few selected projects (i.e., the Montezuma Project and the Crissy Field Project; see diagram on page 13).

Case studies of wetlands projects are also being used to help guide the selection and development of indictors for ambient monitoring and thus increase the likelihood that ambient monitoring will complement project monitoring. Appendix C includes an overview of parameters and indicators used to monitor wetland projects in San Francisco Bay and elsewhere).

The project-monitoring component will progress with the dissemination of data collection protocols, management of data and information for projects, and annual summaries of project status, as the WRMP is woven into a process of project planning and regulatory review.

The use of standard protocols to monitor projects as well as ambient conditions will enable the Steering Committee and the public to compare wetlands projects over time and to one another, relative to ambient conditions. Project monitoring and ambient monitoring will co-evolve, as experience is gained.

Special Studies

The special studies component of the WRMP is needed to advance the science and engineering of wetlands restoration and monitoring, to improve the scientific understanding of natural wetland form and function, and to improve the information technology used to communicate the findings of the Program.

In the near term, special studies will mostly involve development of conceptual models of wetlands form and function, development of indicators of ambient conditions of wetlands, and the development of an information management system. As data are collected and analyzed, they will yield important hypotheses about the causes and effects of the observed conditions, and special studies will be needed to test these hypotheses.

The WRMP is unlikely to develop its own research program. Instead, the WRMP will need to build on the research programs and projects of academic institutions, science NGOs and government agencies that are already well-established research organizations. The WRMP will work with the Management Group of the Restoration Program to define the needs for research and special studies. The WRMP will endeavor to help sponsor the research that is needed.

Much has been said about the scientific and economic advantages of using restoration projects as opportunities to improve restoration approaches and techniques. The WRMP will continue to work with wetlands managers and restoration practitioners to define the questions that might be answered through a process of field tests at project sites. It may be appropriate and useful to build special studies of restoration techniques and monitoring methods into some restoration project designs.

Information Management

The WRMP will include a dedicated information management system. Information management involves data formatting and entry, quality assurance and quality control (QA/QC), storage and retrieval, analysis and interpretation, review and reporting. None of these aspects of information management have been planned in detail. Their general characteristics are outlined below.

Data Formatting and Entry

The heart of the information system will be authoritative data collected with standard protocols, subject to standardized QA/QC, and accessible in standard formats to many user groups. Access to the data should only require common, commercial software and not require custom or proprietary technology.

The Steering Committee anticipates that many different organizations will collect monitoring data, with advice and review by scientific Focus Teams. Special studies and project monitoring might be conducted through the WRMP in some cases.

The database manager will provide standard templates for data formatting. At a minimum, the templates will be designed to allow data users to retrieve and sort data by indicator, habitat type, sampling site, sampling stratum, plot number, data collection method, date, and data collector. Additional data fields or classes will be defined as necessary, subject to review by the Focus Teams and the data authors. Data authors will be responsible for data entry using the formatting templates. It is anticipated that the data authors will remotely upload data into the information system. The data authors will retain all original data sheets and copies of the electronic datasets. The WRMP data managers will work with the authors of GPS data (i.e., data that are appended to geographic coordinates using a Global Positioning System) to create data dictionaries for organizing and labeling data fields in the GPS data loggers.

QA/QC

Data authors provide the first and best level of data protection. They must take full responsibility for the data they collect. They are responsible for using the correct protocols for data collection protocols and for formatting the data correctly for the data managers. They must review the data for numerical and clerical errors, and they must provide the necessary metadata that document the sources of the data and any change in custody of the data.

After the data are carefully reviewed by the data authors and entered into the WRMP information system, the data are subjected to a second level of QA/QC by the data managers. The WRMP data managers will survey each field of data for formatting errors, omissions, incorrect units, and entries that are below known limits of methodological detection or that fall outside acceptable ranges. The data will be plotted as requested by the data authors, who will then examine the plots for evidence of any remaining erroneous or missing data. The data authors upon request by the data managers will provide any missing metadata.

Storage and Retrieval

Data will be stored with the data authors and in the WRMP information system. Data within the system will be backed-up weekly, and the backup copies will be stored away from the data authors and away from the information system at a secured third-party depository that is safe from fire and natural hazards.

Data retrieval or access will be facilitated by a dedicated web site maintained by the WRMP data managers. It is envisioned that the web site will provide access to data and related information through text menus and interactive maps. There may also be active links to sources of other data important to the WRMP but that are collected and managed through other programs. Government agencies and the community of professional scientists will have access to all WRMP data that pass through the QA/QC procedures. To the extent possible, the information system will be compatible with other public-access systems that manage wetland information. The WRMP data managers will strive for a level of compatibility that allows data to move between users without undo delay and without corrupting any datasets. Users will always be able to have their data compared to the original archival datasets that are stored in the WRMP information system.

GIS

A regional geographic information system (GIS) will be a key element of the data management system. The GIS will enable map-based retrieval of spatial data and ongoing accounting of changes in habitat distribution and abundance due to restoration projects and other sources of habitat change. The existing GIS coverages for the baylands that were produced for the Bay Area Wetlands Goals Project will be updated and maintained by the WRMP data managers. These maps are based on the typology of wetlands that the Steering Committee has selected for the WRMP. The Landscape Ecology Team of the WRMP will play a central role in the design and development of the GIS.

Analysis and Interpretation

Once the monitoring data from any given monitoring period are made available to the public, they will be subject to many different analyses and interpretations. However, the Steering Committee and/or Management Group will strive to provide a set of analyses and interpretations according to the authoritative advice and review of the data authors, the Focus Teams, and the Science Review Group. The data authors should participate in the data analyses and interpretations that are conducted through the WRMP. The analyses should be planned before the data are collected. The plans for data analysis should be reviewed by the Focus Teams to assure that the protocols for data collection are followed. The Focus Teams and the Science Review Group should also review any proposed innovations to data analyses. The Steering Committee and/or the Management Group will work with the Science Review Group to help assure that the analyses are interpreted as answers to important management questions.

Review and Reporting

Scientific review will occur in at least five ways. First, informal review of the performance of the WRMP will occur in the normal course of WRMP operations. Focus

Team members will share their products within and among their Teams before the products are released to the Steering Committee and/or Management Group. Second, the WRMP will establish an independent system of refereed peer review for any technical products that are intended for public distribution or use. Data collection protocols and summary reports of scientific findings are examples of such products. Third, data authors and others who conduct original analyses of data that are produced through the WRMP will be encouraged to publish their findings in refereed scientific journals. It is anticipated that the program will help pay for publication costs. Fourth, the WRMP will publish its annual summaries of technical findings, subject to review by the Steering Committee and/or Management Group and the Focus Teams. Fifth, the Management Group will arrange for regular science audits of the program through the Science Review Group. The purpose of these audits is to review and improve the design and functions of the WRMP, pursuant to its mission statement. The data user groups of the WRMP should be involved in the review and revision of the WRMP.

The authoritative interpretations of the data will be the foundation of annual public reports about the findings of the WRMP. One hallmark of the WRMP will be timely, inter-disciplinary interpretations of data to improve the WRMP and to inform wetland management decisions. Data authors and Focus Teams will collaborate on the interpretation of findings. The public will have access to the reports via the Internet. The following chart shows the expected typical schedule of reporting for ambient monitoring, project monitoring, and special studies.

WRMP Component		**Reporting Frequency**
Ambient Monitoring	Tier 1: Landscape Characterization of all tidal wetlands and related habitats	3 to 5 years (GIS will enable landscape scenario planning as needed but summaries of actual change might only be useful every three-five years, depending on the rate of land use change and the rate of implementation of restoration projects).
	Tier 2: Rapid Assessment of randomly selected sites	Annual (additional reporting may occur as special studies and indicator tests.
	Tier 3: Intensive Assessment	Seasonal (additional reporting may occur when intensive ambient monitoring is used in project monitoring to show background variability).
Project Monitoring	Progress Reports	Seasonal or Annual (frequency will differ between indicators)
	Performance Evaluations	Annual (overall progress will be assessed annually for each indicator).
Special Studies	Progress and Completion Reports	Quarterly and Annual (final reports may occur irregularly as technical reports of the WRMP or refereed journal publications

Management Questions and Monitoring Questions

The information needs of the major wetland monitoring efforts in the region have been compiled for the WRMP (see Appendix A) and summarized. These needs have been translated into *management* questions (i.e., what the managers want to know) and the related *monitoring* questions (i.e., what scientists think should be monitored to answer the management questions). The priority questions for the WRMP during FY 2002-03 have been selected based on the following criteria.

Criteria to Select *Management* Questions for WRMP 2001

- *Has the question already been answered, or is it being answered?* If the answer is "yes," then the question is rejected. In these cases, the WRMP should work to communicate the existing answer and to improve communication among the wetland managers and scientists.

- *Can the question be answered in 1-2 years?* If the answer is "no," or "probably not," then the question is rejected at this time. The WRMP should initially focus on important management questions that can be answered quickly. Many questions that have been asked by managers cannot be answered without many years of monitoring or intensive research.

- *Is the question common to multiple programs?* If the answer is "yes," and the question has passed the other criteria, then it is given a high priority. Only a few questions have been asked by more than one program.

- *Can available personnel answer the question?* If the answer is "no," then the question is rejected at this time. The WRMP should endeavor to add funds and partnerships that will increase its technical capabilities.

Criteria to Select *Monitoring* Questions for the WRMP 2001

- *Does the question relate directly to the management question?* If the answer is "no," then the question is rejected. Some management questions have been translated into many monitoring questions, some of which are more direct translations.

- *Can the question be answered by available personnel?* If the answer is "no," then the question is rejected at this time. If the Program grows it will add funds and partnerships that will increase its technical capabilities.

The four questions of highest priority for ambient monitoring have been synthesized from the information gleaned from the major wetland monitoring efforts in the region. The priority questions are: (1) what are the distribution and abundance of wetlands; (2) what are the tidal elevations of estuarine wetlands; (3) what are typical sedimentation rates; and (4) what is the status of wetland plants and wildlife, especially protected species and invasive non-native species.

Science Framework

This science framework is a set of conceptual models that describes the basic forms, functions, controlling processes of tidal marshlands. This framework is a tool, not a product. The WRMP participants can use this framework to remind themselves of the basic technical concepts that are manifest in the program plan. As the WRMP matures, the framework will be modified to reflect new understanding.

The Steering Committee has stated the need for a robust framework of adaptive wetland science and management that will help guide the development of the WRMP. The science framework is therefore general in principal, supports the growth of new ideas, but pertains to the particular nature of tidal wetlands in the region.

The science framework is an outgrowth of recent or ongoing projects and programs that are designed to bring environmental science and management together to protect and conserve the San Francisco Estuary. These efforts include the Comprehensive Conservation and Management Plan of the San Francisco Estuary Project (SFEP), the Regional Monitoring Strategy of the SFEP, the Baylands Ecosystem Habitat Goals Report of the Bay Area Wetlands Ecosystem Goals Project, the Comprehensive Monitoring Assessment Research Program (CMARP) Stage I Final Report of CALFED, the Workshop Proceedings of the Terrestrial Amphibious Monitoring Program of CALFED, the Implementation Strategy of the San Francisco Bay Joint Venture, and the draft Bay Area Wetlands Recovery Program Plan. These projects and programs provide a wealth of information about the kind of wetland monitoring program that should be developed for the region.

These conceptual models have been developed through an iterative process of revision by the Steering Committee. In the spring of 2000, SFEI presented the first versions of conceptual models of program structure and wetland form and function. It was decided by the Steering Committee that the models should be revised based upon the recommendations of the scientific Focus Team. During the summer and fall of 2000, the Focus Team Leaders presented concepts to the Steering Committee that they thought should be represented in the general conceptual models. The presentations made by the Focus Team Leaders varied in breadth and detail, but were individually and collectively adequate to inform meaningful discussions by the Steering Committee.

Based upon these ongoing discussions, the conceptual models have been repeatedly revised, and the Steering Committee has been provided with each new version. This document presents the seventh version of the general conceptual models.

Each of these general models should continue to be subjected to ongoing review and revision as necessary to maintain their usefulness m as useful management tools.

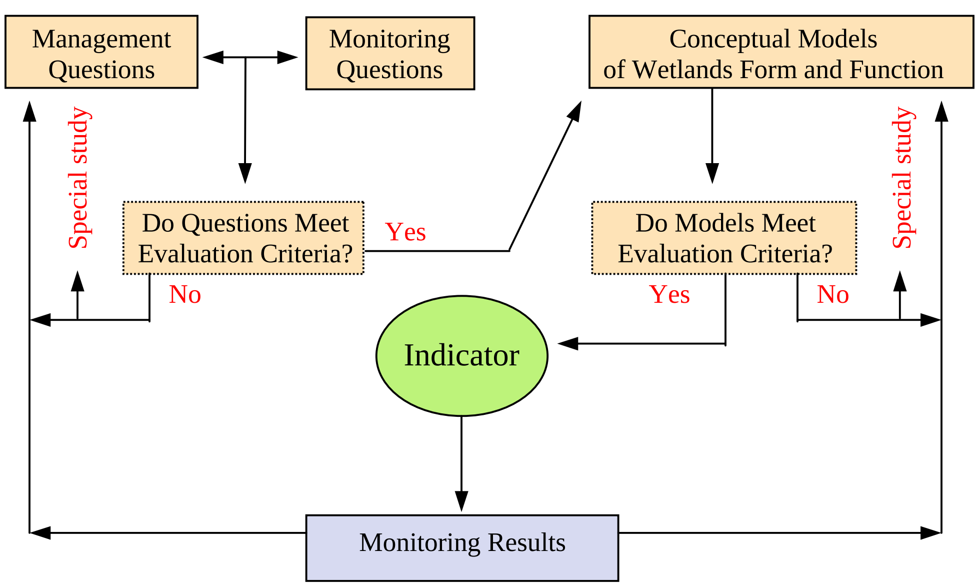
Indicators

For the purposes of the WRMP, indicators are tools for monitoring wetlands to answer management questions. Indicators are methods of data collection and analysis for environmental variables that are selected for monitoring because they are sensitive to management actions. Monitoring data are systematic, repeated measurements using the indicators. Indicators are not always self-evident, however. It is not always obvious how many measurements of what conditions or processes are needed to answer a particular management question. Some indicators must be developed and tested, even to answer questions that are clear and well formulated.

The Steering Committee anticipates that careful definitions of success for wetland projects will lead to the identification of appropriate indicators for project monitoring. Indicators for ambient monitoring must relate to the many management questions that are not project-specific. The Steering Committee has decided to focus on the selection of indicators for ambient monitoring, with the expectation that many of the same indicators will also be appropriate for monitoring projects.

The Steering Committee and/or the Management Group will use the ambient monitoring data to adjust the monitoring questions and management questions. Changes in the questions may lead to adjustments in the indicators. The feedback loops between data, indicators, and questions are the primary pathways of information for improving the WRMP. When indicators and questions are well aligned, then the monitoring results can be used to adjust management actions. This process of self-improvement is termed adaptive management.

Diagram of Indicator Development Process



Adaptive Management and the Pressure-State-Response Model

Adaptive management (Holling 1978, Walter 1986, Bormann et al. 1994) has become a central aspect of resource management by governments (Lee 1999). The Pressure-State-Response-Effects model (PSR) is widely accepted for adaptive environmental management. It is the only model that explicitly links ongoing management actions with ongoing scientific observations.

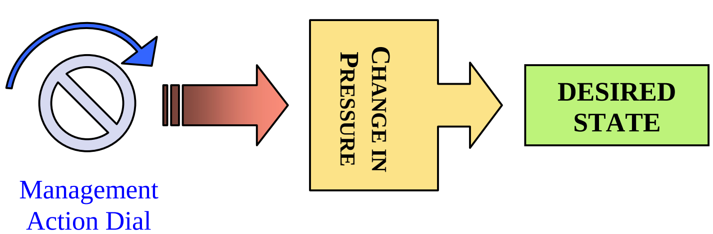
According to the PSR model, human activities exert pressures on populations, communities, and ecosystems and thus influence their state conditions. Adaptive management of a wetland system depends on a flow of scientific information from programs that monitor the states of the system, the pressures that might account for the observed states, the responses of management to the observations, and the environmental effects of the management responses.

According to the PSR model, the status and trends of wetlands can be described by two kinds of indicators. *State Indicators* describe existing conditions or levels of processes. *Pressure Indicators* (also called stressors, driving functions, or controls) help account for the observed state levels. The predictive relationship between levels of a pressure indicator and levels of a state indicator might be mechanistic or statistical.

Over time, data accumulate into sets that can be used to explore relationships between indicators. For example, the ability of a pressure indicator to account for the variability of a state indicator might be tested. There will also be opportunities to explore how combinations of indicators describe or explain conditions better than individual indicators. Such combinations of indicators are termed *Indices*. The number of indices is likely to increase as the length of data records increases, hypotheses are tested, and management questions are refined.

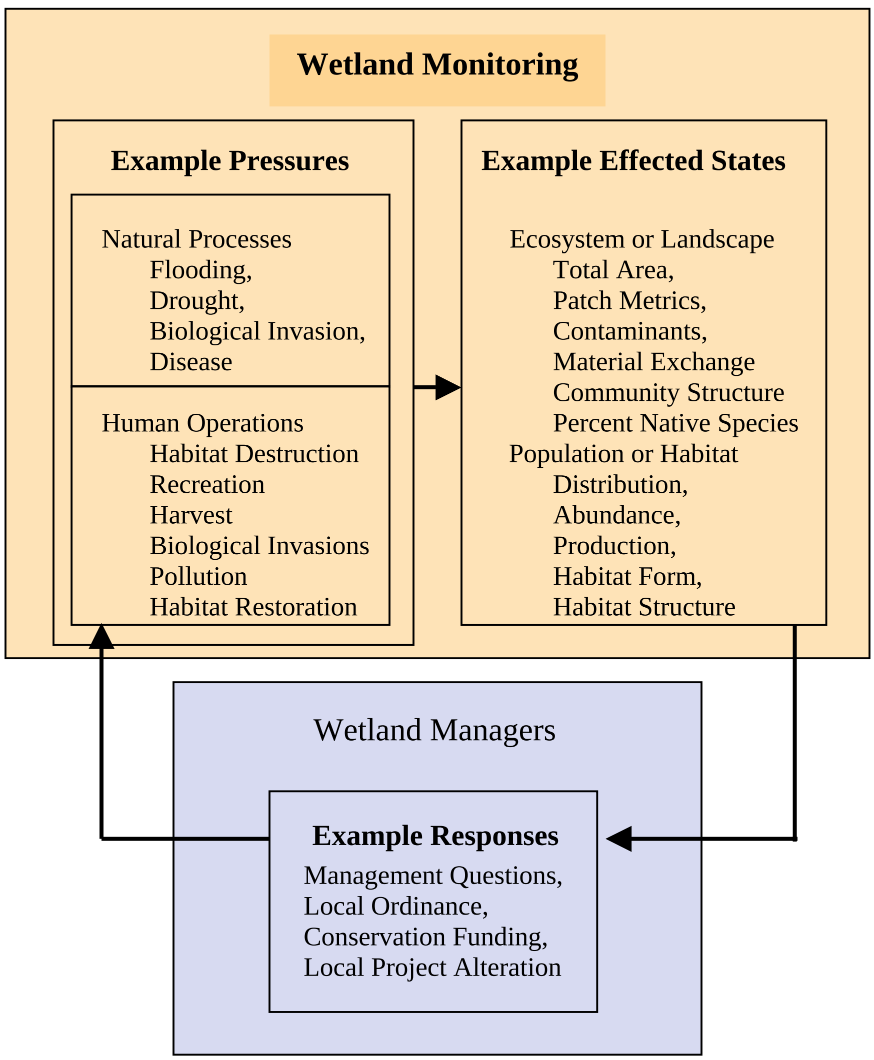
Ideally, long-term monitoring and related special studies reveal the kind of predictable relationships between management actions, levels of pressure indicators, and levels of state indicators that allow wetland managers to adjust their actions such that the desired target levels of the state indicators can be achieved.

Diagram of Monitoring Thresholds and Targets



An example of the PSR model is provided by the response of management agencies to the invasion of the Estuary by smooth cordgrass, *Spartina alterniflora*. Scientists and managers knew the initial introduction, but no management actions were taken. When the invasion began to threaten wetland restoration projects, managers began to monitor the invasion. Since the monitoring began, the invasion has crossed a threshold of concern that has triggered changes in some wetland management objectives. Some managers now regard control of the invasion as part of wetlands restoration.

Diagram of PSR Model



Tidal Wetlands As Transitional Environments

Tidal wetlands link bays and watersheds together. They are therefore strongly influenced by fluvial as well as estuarine processes.

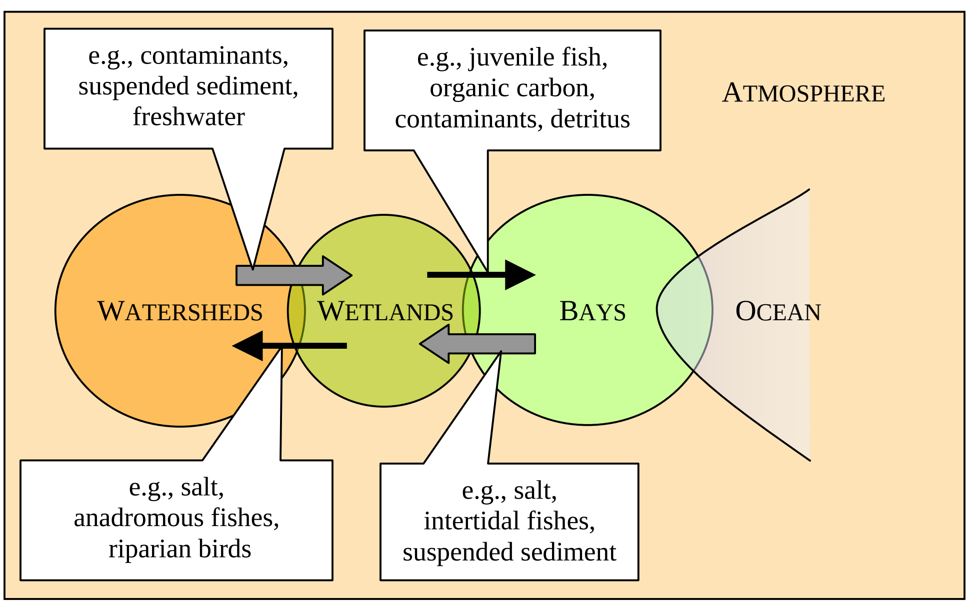
Tidal wetlands and tidal flats represent a net landward direction of estuarine sediment transport from the open bays. This transport is punctuated seasonally due to re-suspension of tidal flat sediments by wind-generated waves. Most of the sediment that enters the marsh is eventually trapped within the channels or on the marsh plain.

Tidal wetlands influence watershed outputs. For example, some of the sediment from local watersheds is stored within mudflats and trapped within tidal wetlands before reaching the bays. Tidal marshes can temporarily store riverine floodwaters and increase the mixing of bay water and river water.

Tidal wetlands have outputs from their own processes that influence bays and watersheds. For example, tidal wetlands are expected to provide carbon to local streams and to the Estuary. They are also expected to serve as nurseries for wildlife, such as fish and waterfowl that disperse to other environments or even to other regions.

Tidal and fluvial processes the affect tidal wetlands vary on six or more time scales. Fluvial processes vary seasonally, annually, and in relation to the irregular schedules el niño or la niña climatic episodes. Tidal processes also vary monthly, bi-weekly (i.e., on the neap-spring tidal cycle), and hourly (i.e., on the mixed-diurnal cycle of the daily tides).

Diagram of Tidal Wetlands as Transitional Environments
(Larger arrows represent larger fluxes of materials or energy)



Interactions between Physical Processes and Vegetation

The evolution and natural maintenance of tidal wetlands depend upon supplies of water and sediment, the former to submerge the land, and the latter to prevent the land from being too deeply submerged.

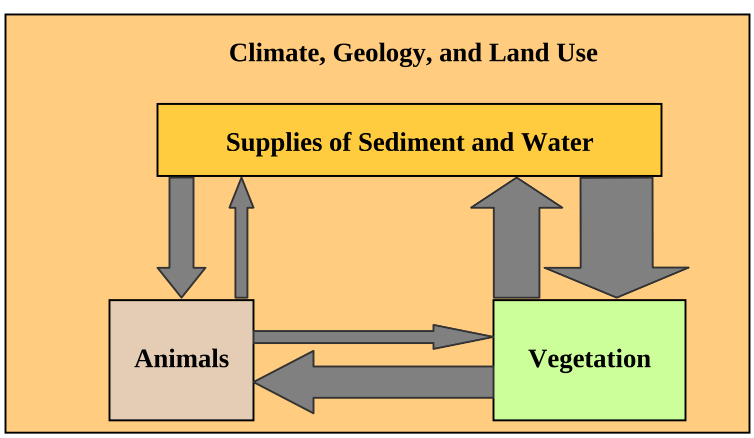
Tidal marshes develop where the accumulation of sediment is equal to or greater than the rate of sea level rise (relative to changing land heights), and there is adequate protection from destructive waves. The supplies of water and sediment are largely controlled by climate, geology, and land use, and therefore they vary throughout the Estuary. The physical conditions conducive to forming tidal marshes are unusual enough that they rarely persist for geologically long time periods.

The effects of sediment and water supplies on tidal marsh evolution are mediated by vegetation. Plants significantly influence sediment availability, sediment deposition, sediment re-suspension, and shoreline erosion due to wave action. Wetlands with peat soils that are produced by plants are subject to subsidence if the peats desiccate and oxidize, and plants can protect wetlands from erosion due to wind. In the San Francisco Estuary, animals are expected to be less important that plants in shaping tidal wetlands. However, burrowing animals can weaken tidal channel banks, and shellfish communities may be important sources of friction that reduces the erosiveness of tidal currents in marsh channels.

The typology of tidal wetlands is primarily based on physical factors. The most important factors for predicting the ecological character of tidal wetlands are tidal elevation and aqueous salinity regime. Many attributes of plant and animal communities vary predictably along gradients of these two factors. Aqueous salinity and tidal elevation are the primary factors for stratifying the tidal marsh ecosystem as a sampling universe.

Diagram of primary factors that control tidal wetland form and function

Climate, geology, and land use control supplies of water and sediment, which in turn control vegetation, which affects the distribution and abundance of animals. Arrows represent hydrology, herbivory, predation, or microbial processes, and point from what controls these processes to what they affect. Larger arrows represent greater responses.



Site Classification

Major environmental gradients that strongly affect the local conditions of tidal wetlands are evident within and between subregions and landscapes.

Subregions and Landscapes

According to the Regional Monitoring Program for Trace Substances, with which the WRMP intends to share data and conduct special studies, the Estuary consists of seven major subregions: Far South Bay, South Bay, Central Bay, North Bay, Carquinez Strait, Suisun, and the Delta. The subregions are based largely on the natural plan form of the Estuary (i.e., the subregions are demarcated in part by natural constructions between broad basins), and on average annual values of aqueous salinity. The subregions could be further segmented by the influence of local watersheds, the distribution and abundance of tidal flats, and by local land use patterns.

A watershed is defined as the lands draining to a common natural channel or storm drain. According to regional convention, the downstream limit of a watershed is its confluence with the tides. This means that tidal marshes are not usually included in watersheds. In order to explore the concept that some watersheds are sources of stress for tidal marshes, a system of marsh classification among watersheds has been developed. According to this classification system, tidal marshes that exists along a tributary river or stream, or that directly receives output from a local watershed are storm drain is part of a *watershed landscape*. Other tidal marshes are regarded as parts of *bayshore landscapes*.

Watershed landscapes greatly complicate the ecology of the Estuary. The local rivers and streams and the major effluent outfalls create their own estuarine gradients that affect estuarine conditions at sub-regional and local scales. These secondary or subordinate gradients are superimposed upon the primary gradient. The ecological variability among the tidal wetlands is affected by all of these gradients.

The size and shape of the Estuary as a whole varies naturally. Measures of shoreline change suggest that some shorelines alternately wax and wane. The tidal prism of local streams and marshes helps maintain the hydraulic geometry of the larger tidal channels that connect the marshlands to the tidal flats and open bays. A change in tidal prism due to changes in stream courses or changes in the rate of sea level rise can cause channels to widen or deepen, if sea level rise accelerates, or to shoal and narrow, if sea level rise slows.

Tidal phenomena and the supplies of freshwater and suspended sediment vary across orders of magnitude of time. Sediment re-suspension due to wave action can happen in seconds. The semi-diurnal tides cause the exposure of intertidal habitats to vary throughout each day. The neap-spring cycles of the tides can cause tidal pumping of saline water into large tidal wetlands during consecutive months. Major ENSO events increase water levels and increase the supplies of suspended sediment and freshwater on 3-7 year intervals. Major droughts have occurred at least once each century. The daily timing of higher high tides relative to the lower low tides varies on a 350-year cycle. And episodes of glaciation that lower sea levels are separated by many thousands of years.

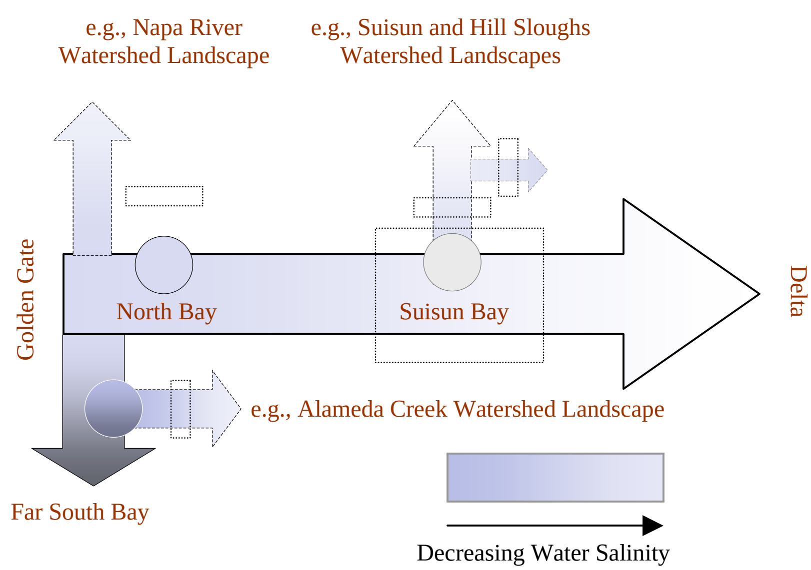
Diagram of Primary and Secondary Estuarine Gradients that Define Bayshore Landscapes and Watershed Landscapes of the San Francisco Estuary

The broad horizontal arrow leading from the Golden Gate toward the Delta indicates the primary upstream gradient of decreasing salinity and tidal range, increasing height of high tide datums, decreasing elevation of tidal wetlands, increasing tidal hydroperiod for tidal wetlands, decreasing channel density for tidal wetlands, decreasing amount of tidal flat, and lower intertidal distribution of vascular vegetation.

The dark arrow leading from the Golden Gate to Far South Bay indicates increasing salinity and tidal range as part of the primary estuarine gradient.

The dashed arrows leading away from the primary gradient indicate secondary gradients into local watershed landscapes. Secondary gradients are steepest in Far South Bay where watersheds drain into very saline conditions. The secondary gradient into Hill Slough from Suisun Slough is unusual in that salinity increases upstream, due to high evaporation rates, scant freshwater inflows, and long residence time for water so far upstream from the primary gradient.

The dotted rectangles indicate zones of maximum turbidity, and the circles represent amplification of the tidal range due to standing waves near the mouths of local rivers and streams.



Stratification within Habitat Patches

The status, trends, and ecosystem effects of management actions, including the effects of wetland restoration projects, can be measured at five nested spatial scales: the Estuary as a whole, subregions of the Estuary, landscapes or watersheds within the subregions, habitat patches within the landscapes, drainage systems within the habitat patches, and shorelines or other geomorphic features of the drainage systems. The appropriate scale of assessment will differ among the indicators.

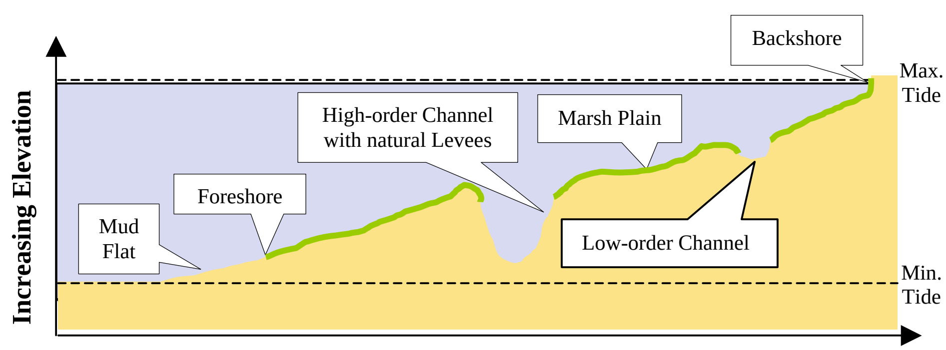
A tidal marsh drainage system consists of the area of a marsh that drains to a single channel. Given the dendritic form of tidal marsh channel networks, small drainage systems tend to be nested in larger systems. By regional convention, the smallest channel having an unvegetated seepage face but lacking any tributaries is termed first-order. The confluence of two or more first-order channels marks the upstream end of a second-order system; the confluence of two or more second-order systems marks the start of a third-order system, and so forth.

The dominant geomorphic features of a tidal marsh that might be designated as sample strata include the foreshore (i.e., the boundary between the tidal flat and tidal marsh), the back shore (i.e., the boundary between the tidal marsh and the upland, channel banks, natural and man-made levees, the vegetated marsh plain between channels, and panes (i. e., shallow depression on the marsh plain that do not always drain at low tide).

Within-site Stratification

Five sampling strata are self-evident within most saline and brackish tidal wetlands: (1) small channels (first- and second-order); (2) large channels (third-order and larger); (3) foreshore; (4) backshore; and (5) the marsh plain. The five major sampling strata (not including mud flat) are predictably distributed along the profile of elevation in a tidal marsh.

Elevation Profile of Within-Patch Sampling Strata

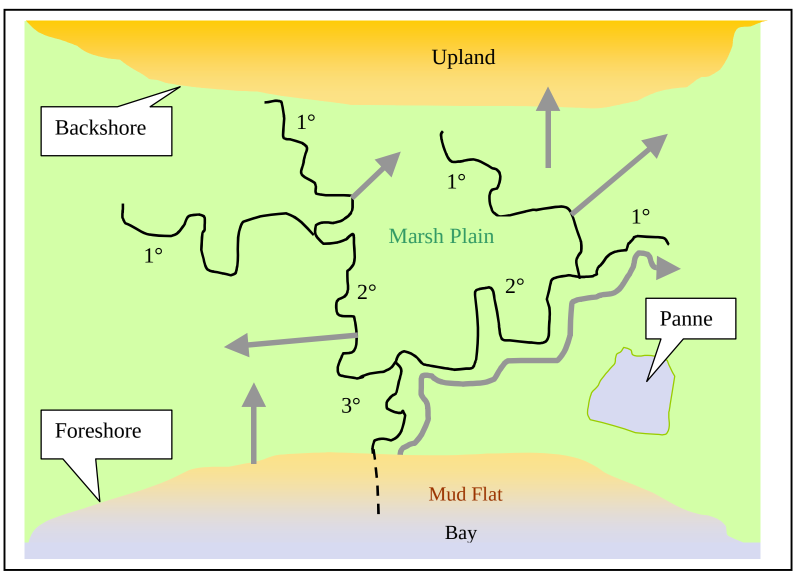


Patches of freshwater tidal marshes and some immature or very narrow saline marshes lack internal channels. In these marshes, and in tidal flats that lack vascular vegetation, the obvious strata are the foreshore, backshore, and plain.

These strata can be used to partition the sample variance between natural hydrological and geomorphic processes, such that the statistical power of data to compare one habitat patch to another is increased. The strata can also be aggregated in a sampling scheme that maximizes variability. For example, the strata might be sampled together to assess the heterogeneity of habitat structure within a patch, or to assess its overall species richness.

Plan View Diagram of Basic Within-site Sampling Strata
For a Third-order Tidal Marsh System

The gray arrows point toward increasing elevation and distance from tidal source as proxies for decreases in tidal hydroperiod, decreases in tidal datum, decreases in tidal range, decreases in suspended sediment supply, increases in soil organics, decreases in soil pH, decreases in plant height and plant diversity (except perhaps in brackish and fresh tidal marshes and across the foreshore and backshore) and increases in the geomorphic importance of biotic processes compared to abiotic processes.

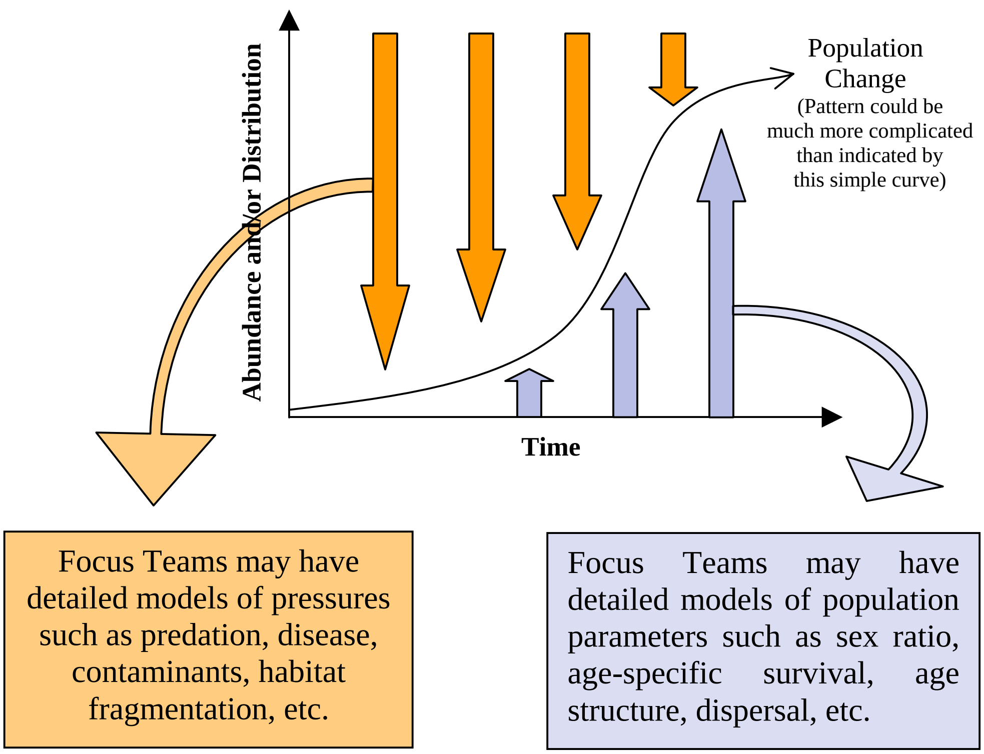


<u>Plant and Animal Population Indicators</u>

This model assumes that changes in state conditions for populations of tidal marsh plants or animals relate in large part to changes in environmental pressures, such as predation, flooding, fluctuations in food resources, etc. These pressures vary through space and over time in kind, frequency, duration, intensity, and magnitude. The population responses are also variable, being in some cases density-dependent, age-specific, and seasonal. State indicators can include the distribution, abundance, density, standing stock, survivorship, or productivity of selected populations. Pressure indicators will also differ among populations but will usually represent habitat quality, habitat quantity, or some form of inter-specific interaction, such as predation or competition.

There are a variety of reasons to select populations of plants and animals as state indicators of the conditions of wetlands. They may be protected species that should be monitored to assess the effects of conservation efforts, or they might have prevalent ecological functions as keystone predators, common food resources, ecological engineers, disease vectors, or links between tidal wetlands, bays, and local watersheds.

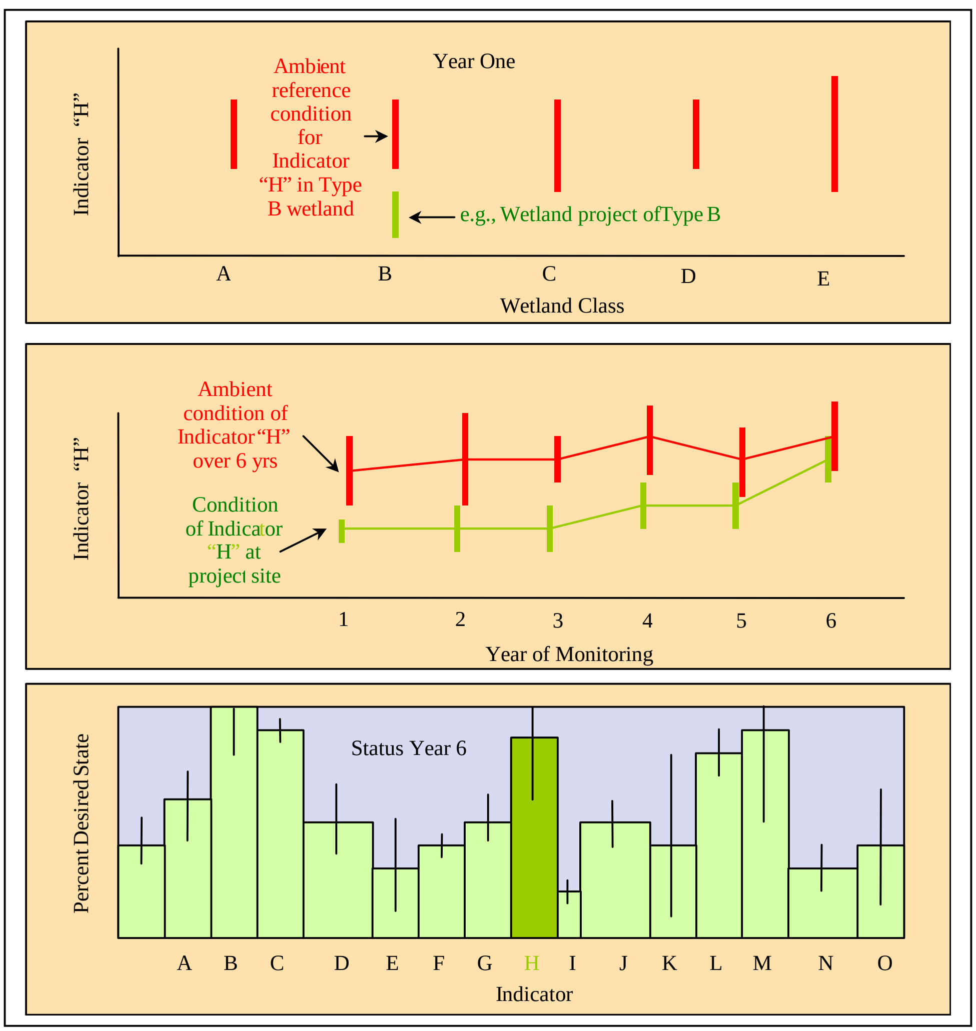
Simple Diagram of State and Pressure Indicators for Populations



Assessment Models

Comparable methods are used to assess ambient conditions and project performance. Projects are included in the regional assessment of ambient conditions. Furthermore, the ambient data are classified by major wetland type, such that projects can be compared to reference conditions (i.e. ambient conditions for the same class of wetland as the project).

The following hypothetical graphs illustrate the final stages of data analysis for indicator "H". The bottom graph shows how the data can be used to report an overall score between 1 and 10 for one site, a group of sites, a subregion, or for the population of wetlands as a whole. The upper limit of the bottom graph must be set to represent 100% of either the desired, mandated (i.e., legally required), or ambient state condition for each indicator in the graph. The area of the graph covered by the bars represents "percent of good health." This method provides a single quantitative measure without concealing any data. It is visual as well as numeric, and is therefore easy to understand. It shows the error of the estimate. It can be used for any combination of indicators. It is independent of scale. And any indicator can be weighted simply by changing the width of its bar.



Selected Indicators

<u>The Candidate Indicator Set</u>

Integration of the 3-tiered monitoring approach (see page 13) with the Pressure-State-Response model of adaptive management (see page 22) suggests that ambient monitoring can involve pressure and state indicators for landscape characterization (tier 1), rapid assessment (tier 2), and intensive assessment (tier 3).

The WRMP has focused on tier-3 pressure and state indicators that could be used for either ambient monitoring or project monitoring. Tier-1 and tier-2 indicators will be developed during FY 2002-03.

The Focus Teams have nominated a broad range of tier-3 indicators. The nominations followed from a review of indicators that are used in other monitoring efforts in this region and elsewhere (see Appendix C), plus the criteria listed below.

Criteria to Nominate Indicators for Ambient Monitoring or Project Monitoring

- **?** *Does the indicator reflect the state of the science?* If the answer is “no,” then the indicator is rejected or slated for revision.

- **?** *Does the indicator reflect the conceptual models of wetlands form and function of the Science Framework?* If the answer is “no,” then the indicator is rejected, or the models must be revised.

- **?** *Will the indicator efficiently answer a priority monitoring question?* If the answer is “no,” then the indicator is rejected. Some indicators require more development to directly address the monitoring question.

- **?** *Does the indicator serve more than one function?* If the answer is “yes,” and the indicator has passed the other criteria, then it is given a high priority. Some indicators serve as both pressure indicators and state indicators, or they pertain to more than one monitoring question.

The indicators that were nominated by the Focus Teams have been arrayed in a matrix that shows their relationships to each other and to the major compartments of the tidal marsh ecosystem (see Appendix D). According to this matrix, each of the state indicators is also a pressure indicator for more than half of the ecosystem compartments. Furthermore, about half of the indicators link two or more compartments together. The large amount of inter-dependence among the indicators signals a need for close coordination among the data authors and their easy access to each other’s data.

Indicators Selected for Protocol Development in FY 2001-02

Most of the protocols that have been developed or that are scheduled for development during FY 2002-03 are considered to be fundamental for ambient monitoring and/or project monitoring. Additional protocols will be developed for candidate indicates (see Appendix D) over the next few years. All the protocols will occasionally need to be revised to reflect new scientific understanding.

Based on the priority management questions and the conceptual models, the most important protocols for monitoring tidal marshes at this time are for project mapping, tidal elevation, sedimentation, contamination, plant community structure, status of protected species, and avian support.

Monitoring Activity	**Indictors Selected for Protocol Development In FY 2002-03**	**Schedule of Protocol Development**
Landscape Characterization	Wetland mapping and characterization for tracking projects	Winter 2002-03
	Watershed-based human population demographics	Winter 2002-03
	Wetland habitat fragmentation and connectivity	Winter 2002-03
	Wetland buffer structure and composition	Winter 2002-03
	Wetland habitat patch size-frequency	Winter 2002-03
	Tidal marsh channel density	Winter 2002-03
Rapid Assessment of Projects or Ambient Status and Trends	Wetland patch size	Summer 2003
	Buffer condition	Summer 2003
	Hydrology	Summer 2003
	Habitat alteration	Summer 2003
	Habitat uniqueness	Summer 2003
	Micro-topography	Summer 2003
	Plant community type	Summer 2003
	Plant species diversity	Summer 2003
	Non-native invasions	Summer 2003
	Plant cover	Summer 2003
Intensive Assessment of Projects or Ambient Status and Trends	Datum reckoning and tidal elevation	Winter 2002-03
	Sedimentation-erosion tables	Available
	Tidal marsh contaminants	Available
	Plant community structure	Available
	Benthic macroinvertebrate community	Available
	California red-legged frog	Available
	Salt marsh harvest mouse	Available
	River otter	Available
	Yuma bat	Available
	Herons and Egrets	Available
	Gulls and Terns	Available
	Passerine birds	Available
	Rails	Available
	Shorebirds	Available
	Waterfowl	Available

Sampling Approaches

The wetlands of the region are too numerous and diverse to exhaustively assess all the wetland sites or patches during any reasonable period of time (see page 26), using either the tier 1 (rapid assessment) or tier 2 (intensive method). The regional assessment of wetland condition must therefore be based on observations for a subset or sample of the sites. Likewise, most individual patches of tidal marsh are too large or too complex to be assessed without focusing on subareas or sampling strata within the patches.

The WRMP must therefore rely on a sample of the wetlands to assess their ambient conditions. The challenge is to optimize the sample for cost and information content. The monitoring efforts must yield data that are reasonably representative, accurate, and precise. The optimal approach will involve the fewest data necessary to address the most important questions with acceptable levels of uncertainty. The WRMP should strive to improve these aspects of the program by refining the management questions, the sampling strata, indicators, and methods of data collection. As the data record grows for wetland monitoring, it should be used to test the efficacy of the sampling approaches and to adjust the size of samples. The Tier 3 aspect of ambient monitoring provides the necessary testing of assumptions and methods.

Different sampling approaches might be tested through the WRMP during the next few years, with advice and review from the statistical support team. Although a change in approach can break the record of data, it may not be possible to start data collection with the same approach that will ultimately be used. The sampling approach is likely to evolve, as will the indicators and their protocols.

Much might be learned from trying a variety of sampling approaches during the early stages of the WRMP. It is expected that during FY 2003-04, a variety of approaches will tried through CALFED's special study of ecosystem effects, EMAP's West Coast wetlands assessment, and implementation of EPA's the 3-tiered monitoring scheme (see page 13).

<u>Selecting Ambient Monitoring Sites</u>

No ambient wetland monitoring program exists for the region at this time. Ambient conditions are typically monitored only at one or two "reference sites" for each wetland mitigation project to judge its performance. This approach can answer the question: "is the project similar to the selected reference sites," but it does not answer the questions, "what is the ambient status and trends of wetlands in the region," or "how does the project compare to the ambient data for comparable wetlands?" To answer these questions, the ambient monitoring component of the WRMP will need to adopt a new approach to site selection.

The two basic approaches to the selection of ambient monitoring sites are termed "fixed," and "probabilistic." The fixed approach involves monitoring the same "reference sites" or "control sites" during each sampling effort. In this sense, the habitat patches that are used as sample sites are fixed, or permanent. This approach can yield long-term datasets and detailed understanding for the selected habitat patches. A modification of this approach allows the sampling program to rotate every few years among a few different sets of fixed sites. This modification increases the number of sites over time, but a data gap is incurred periodically for each site. It is important that each set of fixed sites include representatives for each major type of wetland and each subregion of the geographic scope of the WRMP.

The probabilistic approach features a random selection of sites from the population of all possible sites in the region. There are no fixed or permanent reference sites or control sites. For the types of sites that are sampled, the monitoring data are broadly representative of the region and subject to the least bias.

For either approach, the monitoring effort is distributed among the major types of wetlands of interest, and among the sampling strata within each patch (see pages 28 and 29). The effort can be distributed at random within the strata (i.e., the “stratified-random approach”), or sampling stations can be fixed within each stratum.

The least biased and broadest representation of regional tidal marsh conditions would be achieved through stratified-random sampling within randomly chosen sites for each major type of tidal marsh. This approach can be simplified by focusing on a subset of the habitat types, but the results will not be transferable to other types that are not sampled. The most biased and narrowest representation of conditions would result from monitoring fixed stations in one stratum at one fixed site. Many variations within these extremes are possible, but only one scheme will be optimal. Again, the challenge is to develop a sampling approach that provides a cost-effective and adequately certain answer to an important management question.

The critical first step in either random or non-random sampling is therefore careful formulation of the questions to be answered. The Chairs of the Steering Committee and/or the Management Group as well as the Science Coordinator for the WRMP should be able to state what question will the data address and how certain does the answer need to be. This will lead to decisions about what sampling approach to use, how many different strata and wetland types should be sampled, and how large a sample is required.

Examination of the management questions and monitoring questions assembled by the Steering Committee (see p. 18) reveals the need for a broad assessment of tidal marshes throughout the region. For example, there is a need to assess the structure of plant and animal communities across the range of marsh age (i.e., elevation) and salinity. Otherwise, the regional assessment of ambient status and trends will be biased toward a subset of conditions, and the ambient dataset will not support the evaluation of basic performance for some projects.

Wetland projects can be included in the population of ambient monitoring sites. Projects can provide important opportunities to understand early stages of wetlands evolution and community development. Furthermore, wetland projects should be compared to ambient sites of comparable age. The population of project sites may yield a useful dataset for assessing the variability of conditions among projects of similar age, structure, and salinity.

Different indicators might be used at different site. The intent, however, should be to monitor all indicators at each site. This will encourage collaboration across disciplines, the development of indices based on combinations of indicators, the testing of correlations between state and pressure or response indicators, and the most integrative assessments of site-specific and regional conditions.

Selecting Wetland Projects to Monitor

The sponsor of a wetland project might turn to the WRMP for review of monitoring plans and results, for training in the use of the data collection protocols, for managing the project data, and for conducting the monitoring. The following criteria have been developed to guide the Steering Committee of the WRMP and/or the Management Group of the Restoration Program in the selection of wetland projects for the WRMP.

The Steering Committee and/or Management Group will need to finalize criteria for choosing wetland projects to be addressed by the Design Review Group and to be subject to intensive monitoring through the WRMP. In every case, the WRMP will strive to at least provide standard protocols for data collection and data management

Considerations for Selecting Projects
For the Design Review Group and the WRMP

- *Is the project ecologically significant?* A project might be ecologically significant because it is large, involves major ecotones, could restore rare habitat or support rare or threatened species, could support unusually diverse native communities, or could function as critical refugia or as a migratory corridor for wildlife. If the answer is “no,” then the Steering Committee and/or Management Group must weigh the value of monitoring the project relative to other projects, given that the WRMP will not be able to intensively monitor all projects.

- *Is the project economically significant?* A project might be economically significant because it reduces flood hazards, serves as a depository for dredged sediments, curtails dredging by providing the tidal prism that maintains channels, or supports recreation. If the answer is “no,” then the Steering Committee must weigh the value of monitoring the project relative other projects.

- *Does the project present special learning opportunities?* A project may be important because it can be used to develop or test new ideas about restoration design, engineering, or monitoring.

Funding Approaches

One or more of the following approaches may serve to create a mechanism for long-term financial support of the WRMP.

MOU Approach

Memoranda of Understanding would be negotiated between all agencies and other organization that are responsible for carrying out wetlands restoration and mitigation projects. The MOU would commit each agency/organization to participate in the WRMP. Participation would include using the protocols for data collection and data management that are developed by the WRMP, and setting aside of a portion of the project monitoring funds for support of the WRMP. Ideally, a percentage of all project costs would be set aside for monitoring. Part of the set aside would be used by the WRMP to subcontract for data collection, and part for general program support.

Fee Approach

In this approach, monitoring “fees” would be imposed through project permits in lieu of monitoring requirements. The fees would be deposited in a WRMP fund to pay for project monitoring and reports. This approach assumes that not all projects will be monitored.

Legislative Initiative Approach

Funds to track restoration progress could be built into regional, state, or federal initiatives to support wetland restoration. Monitoring requirements and funding to support the WRMP would be part of the initiatives.

Land Purchase Price Approach

The price tag for public purchases of lands intended for restoration could include the costs for monitoring.

Marketing Approach

The WRMP could aggressively market its protocols and data management capability to private and public wetland project sponsors. By doing a lot of monitoring and by managing the data in consistent ways, the WRMP would amass large amounts of data that could be used to further market the WRMP. This approach puts a premium on regional datasets.

Volunteers and Foundation Approach

The WRMP would work with the member agencies of the Wetland Restoration Program to get the standard protocols written into project permits, and would work with project sponsors to obtain all monitoring data for generating regional assessments. The WRMP would then compete for grants from foundations and agencies to initiate long-term funding.

Endowment Approach

The WRMP would seek to obtain funds from a court settlement, large-scale mitigation project, or other multi-million dollar source as an endowment that would generate sufficient funds to support the WRMP entirely or in part.

The following table lists some of the probably advantages ands disadvantages of each of the funding approaches outlined above.

Approach	Pros	Cons
MOU	▪ Could begin immediately. ▪ Existing MOUs could be used to leverage others. ▪ No law or regulation change required.	▪ A lot of work to set up. ▪ Not every agency may want to participate. ▪ Contracting with many agencies increases administrative costs.
Fees	▪ Might be done with little or no increase in current monitoring costs. ▪ Is easy to administer once in place.	▪ Depends on wetland alteration (negative image). ▪ Will tie WRMP closely to wetland regulation. ▪ Will require a champion agency.
Legislation	▪ May be the most transparent and straightforward approach. ▪ Would be tied to restoration (positive image).	▪ Requires legislative champion. ▪ May requires rallying political support of NGOs and private sector.
Marketing	▪ No law or regulation change required. ▪ No agency champion needed.	▪ Consulting mode may undermine neutrality. ▪ WRMP might not compete well against large consulting firms. ▪ Holes in the market mean holes in the regional data record.
Volunteers and Foundation	▪ No law or regulation change required.	▪ Not a long-term solution.
Endowment	▪ No law or regulation change required. ▪ Is secure and long-term. Allows independence and neutrality.	▪ There is no sure source. ▪ WRMP could lose touch with agency needs.

Appendix A

Compilation of Wetland Management Questions

This appendix lists the wetland management questions and monitoring questions that have been asked by CALFED, the WRMP, the Suisun Marsh Monitoring Program, and the Bay Area RMP for Trace Substances, as the major wetland planning or monitoring efforts in the Estuary.

The CALFED questions are based on the Summary of Comments from the Tidal Wetlands Monitoring Workshop that was held by CALFED on September 7, 2000. Questions have been combined if their answers require very similar monitoring data. Some questions were separated into their obvious major components. Questions that appear in the proceedings but that do not pertain to tidal wetlands are not represented here because they do not pertain to the pilot effort of the proposed monitoring Program.

The WRMP questions represent a combination of questions that were listed by the WRMP Steering Committee in October 2000, and additional questions that were provided later by some Science Teams of the WRMP. Questions have been combined if their answers require very similar monitoring data.

Questions from the Suisun Marsh Monitoring Program are derived from version 2 of the Suisun Marsh Monitoring Program Reference Guide that was produced by the California Department of Water Resources in June 2000. This document supplements the Suisun Marsh Monitoring Program Data Summary reports for 1988 through 1997, pertaining to compliance monitoring of marsh conditions under the Suisun Marsh Preservation Agreement of 1987. The objectives of the program therefore relate directly to monitoring for compliance with this Act. The management questions, other than the overarching question about compliance, are inferred from the monitoring requirements that are bulleted on pages 45 and 46 of the Program Reference Guide. Some of the monitoring requirements were separated into their obvious major component questions.

Questions from the Regional Monitoring Program for Trace Substances were derived from the document titled “Draft RMP Management Questions” dated April 2, 1998. Within this document, the questions are divided into two groups, Focusing Questions and Specific Management Questions. The Focusing Questions are more general and may be most applicable to the pilot effort of the proposed wetland monitoring program.

These questions can be classified among three spatial scales and seven ecological compartments of the tidal wetlands system, according to the science framework. The seven system components are (1) physical processes, (2) contaminants, (3) plants, (4) invertebrates, (5) fish, (6) amphibians, reptiles and mammals, and (7) birds. But some questions pertain mainly to the direct effects of people, which might there be considered as a separate component of the ecosystem.

Source Codes for the Wetland Questions

CF	CALFED
WRMP	Bay Area Wetlands Regional Monitoring Program
SMP	Suisun Marsh Monitoring Program
RMPTR	Bay Area Regional Monitoring Program for Trace Substances

Regional or Subregional Scale (could also apply to Local and Landscape Scale)

Physical Processes

Management Questions

Where are the wetlands? CF, WRMP

Related Monitoring Questions

What is the distribution of each type of wetland? CF, WRMP

Is the wetland ecosystem fragmented? CF, WRMP

What are the sizes of the wetlands? WRMP

What is the ecological connectivity among habitat patches? CF

How big is the Estuary, and how is its size changing, and what are the effects of sea level rise? CF, WRMP, SMP

What are the tidal statistics, including the average value and variability for the tidal prism, tidal datums, tidal range, stage height frequency, salinity of the surface waters, and tidal lag times of the wetlands, relative to the Golden Gate? WRMP, CF, SMP

What are the total lengths of the backshore and foreshore of the tidal wetlands, including the tidal marsh channels? WRMP

What are the plan-forms and locations of the backshore and foreshore of the Estuary, including the tidal marsh channels? WRMP

What are the average elevations of the wetlands? CF, WRMP

What is the tidal prism of the wetlands system? CF, WRMP

What are the distribution and abundance of tidal marsh channels? CF

What are the status and trends in the salinity gradients? CF, SMP

What are the soil bulk densities, organic factions, and hydrogen ion concentrations (pH) of the root zones of the habitat types, and how do these vary along gradients of elevation and distance from water sources within the wetlands? WRMP

Management Questions

Is there enough sediment for tidal marsh restoration?

Related Monitoring Questions

What is the annual supply of suspended sediment within the swallow subtidal and intertidal environments? WRMP

What are the sediment trapping efficiencies of the intertidal habitat types? WRMP

What are the rates of horizontal and vertical changes in elevation of the intertidal habitat types, due to accretion, erosion, or subsidence? WRMP

How are the wetlands physically linked to the uplands and to the bays? WRMP

What proportions of the suspended sediment supply come directly from terrestrial versus estuarine sources?

What is the extent of the freshwater effects from local rivers and streams on intertidal salinity gradients?

Contaminants

Management Questions

What are the concentrations of contaminants in wetlands? CF, SMP

Related Monitoring Questions

What are the concentrations of heavy metals and organic contaminants within the surface waters and root zones of wetlands, and how do these concentrations vary along gradients of elevation and distance from water sources within the habitat types?

What are the patterns of change in concentration of contaminants along common food chains involving native wetland plants and animals, such as the food chain involving detritus, amphipods, song sparrows, and harriers?

What are the distribution and abundance of methyl mercury in wetlands and tidal flats, relative to known patterns of sediment and water movement and retention? WRMP

Which contaminants bioaccumulate in estuarine organisms to levels of concern? RMPTR

What is the spatial and temporal extent of toxicity in the Estuary, and which contaminants cause this toxicity? RMPTR

Plants

Management Questions

What are the distribution, species composition, and abundance of plant communities? CF

Related Monitoring Questions

What is the species richness for each major wetland habitat type and for the landscape as a whole? WRMP

What is the ratio of native to invasive non-native species for each habitat type and for the landscape as a whole? WRMP

For each habitat type, what are the major-dominant plant species? WRMP

What is the phenology of the major-dominant plant species? WRMP

Within each habitat type, what is the pattern of change in plant community species composition along gradients of elevation and distance from sources of surface water? WRMP

Within each habitat type, what is the quality of vegetation as habitat for indicator species or assemblages of invertebrates, fish, amphibians, reptiles, mammals, and birds? WRMP

What are the new introductions of non-native plants? CF

What are the production rates of waterfowl forage plants and other key plant species? SMP

What are the distribution and abundance of special status plant species? CF, WRMP

What are the status and trends in distribution and abundance of detrimental, invasive, non-native species of plants, including smooth cordgrass, giant reed, and broad-leaf peppergrass? CF, WRMP

What are the distribution and abundance of the native wetland plants of special legal status, including the Suisun thistle, Suisun Marsh aster, Mason’s lilaeopsis, Point Reyes bird’s beak, and soft bird’s beak? CF, WRMP

Invertebrates

Management Questions

What do wetland birds and fish eat?

Related Monitoring Questions

What are the distribution and abundance of fish and bird prey items? CF

What are the distribution and abundance of *Neomysis*? SMP

Besides being food, what else do macroinvertebrates do? WRMP

What are the pollinators and other critical invertebrate associations with native wetland plants? WRMP

How does the benthic invertebrate community indicate salinity and contaminant levels? WRMP

What invertebrates provide pathways for bioaccumulation of contaminants? RMPTR

What is the distribution of mosquitoes as disease vectors? WRMP

Fish

Management Questions

What fish use tidal wetlands? CF, WRMP

Related Monitoring Questions

What are the distribution, species composition, and abundance of the wetland fishes? SMP, WRMP

What are the distribution and abundance of the native wetland species of special legal status, including Delta smelt, longfin smelt, green sturgeon, Sacramento splittail, Sacramento perch, Chinook salmon, and steelhead? CF, WRMP

What are the distribution and abundance of young striped bass? SMP

What is the ratio of native to invasive non-native species for each habitat type and for the landscape as a whole? WRMP

What are the linkages between wetlands and uplands and the bays? WRMP

What bay fishes use tidal wetlands? WRMP

What anadromous fishes use tidal wetlands? WRMP

Amphibians, Reptiles, and Mammals

Management Questions

What are the distribution and abundance of special status species?

Related Monitoring Questions

What are the distribution and abundance of the native wetland amphibians of special legal status, including the red-legged frog and tiger salamander? CF, WRMP

What are the distribution and abundance of the native wetland reptiles of special legal status, including the giant garter snake and western pond turtle? CF, WRMP

What are the distribution and abundance of the native wetland mammals of special legal status, including Suisun ornate shrew, salt marsh harvest mouse, San Pablo California vole, riparian brush rabbit, and harbor seal? CF, WRMP

What are the distribution and abundance of invasive non-native species and their control efforts? CF, WRMP

What amphibians, reptiles and small mammals inhabit the wetlands?

What is the species richness for each major wetland habitat type and for the landscape as a whole? WRMP

What are the distribution and abundance of wetland mammals as predators? WRMP

What are the linkages between wetlands and uplands and the bays?

What species of amphibians and reptiles move between uplands and wetlands to breed?

What species of mammals move between uplands and wetlands to forage or seek refuge?

Birds

Management Questions

What birds use tidal wetlands? SMP, CF. WRMP

Related Monitoring Questions

What are the distribution, species composition, and abundance of waterfowl? CF, WRMP, SMP

What are the distribution, species composition, and abundance of wading birds? CF, WRMP

What are the distribution, species composition position, and abundance of shorebirds? CF, WRMP

What birds of special status use the wetlands? CF, WRMP, SMP

What are the distribution and abundance of the California clapper rail, California black rail, intertidal song sparrows, burrowing owl, bank swallow, snowy plover, least tern, tidal marsh common yellowthroat, and Swainson’s hawk? CF, WRMP

What is the species richness for each major wetland habitat type and for the landscape as a whole? WRMP

What level of support do tidal wetlands provide for migratory birds?

People

Management Questions

What are the values of wetlands to people?

Related Monitoring Questions

What are the common commercial or recreational uses of wetlands, such as dredged sediment disposal, hunting, fishing, hiking, boating, and bird watching, and how are these use distributed? WRMP

What are the distribution and abundance of different land uses that border the wetlands, and do the wetlands affect thee uses? WRMP

What are the costs of mosquito and vector control for tidal wetlands as compared to other wetlands?

What are the distribution and abundance of tidal wetlands as parks, open space, or other kinds of public lands?

What is the rate of wetlands loss due to the activities of people?

What are the management actions?

What is the distribution and size class frequency of wetlands restoration and mitigation projects? CF, WRMP

What is the total amount of money spent for wetland management, including habitat restoration or mitigation, facilities maintenance, and enforcement of environmental rules and regulations? WRMP

What environmental regulatory permits have been requested, granted, or denied, and what wetlands are affected? WRMP

Landscape Unit or Local Project Scale

Physical Processes

Management Questions

What are the best habitat designs? WRMP

Related Management Questions

What distribution, abundance, and configuration of habitat elements, such as channels large and small, levees, and tidal pans or seasonal wetlands, are best suited for any particular project objective? WRMP

What are the environmental criteria for prioritizing projects? WRMP

What are the ecological and geomorphic indicators of project success or performance? WRMP

What effects do projects have on each other? CF, WRMP

Do interactions between habitat patches affect the suspended sediment supply, tidal statistics, or wildlife movements? CF, WRMP

Contaminants

Management Questions

How do contaminants affect projects success or failure? WRMP

Related Management Questions

What is he distribution and abundance of mercury and other contaminants? WRMP

Of the national priority pollutants, which ones are found in the Estuary system and of those, which ones are at levels that may be causing effects? RMPTR

Are the sources controllable, and if so, under what existing regulatory framework? RMPTR

How are these patterns changing in response to natural processes and progressive management actions? RMPTR

What is the relative contribution of point source outfalls, storm drains, large and small tributaries, harbor activities including dredging, atmospheric deposition, historic deposits, and natural sources? RMPTR*

How effective are management actions? RMPTR.

What are the background concentrations of contaminants in the Estuary from natural sources? RMPTR, WRMP

How have past management actions affected the overall patterns of levels, fate, and transport of pollutants of concern? RMP

APPENDIX B

Conceptual Models of the Science Framework

Conceptual models of natural systems are useful tools to organize existing information, identify information gaps, and, when the information base is adequate, predict system response to internal perturbations or changes in boundary conditions. Recent empirical studies of tidal marsh geomorphology based in San Francisco Bay serve as a foundation for building conceptual models of tidal marsh form and evolution. Less is known about the tidal flats in the region, but their fundamental nature can be surmised from studies of similar system elsewhere. The models presented below, in conjunction with the assumptions that follow, are used to help predict the local and regional geomorphic effects of the smooth cordgrass invasion on the intertidal zone.

Adaptive Management

Adaptive management (59, 60, 61) of natural resources requires regular inputs of empirical data about the variability in form and function of the resources that can be used to assess the risk associated with management actions. Adaptive management has become a central aspect of resource management by governments (62).

The Pressure-State-Response-Effects model (PSR) is widely accepted for adaptive environmental management. It was among the first models to explicitly link ongoing management actions with ongoing scientific observations (63).

According to the PSR model, human activities exert pressures on populations, communities, and ecosystems and thus influence their state conditions. Adaptive management of a wetland system depends on a flow of scientific information from programs that monitor the states of the system, the pressures that might account for the observed states, the responses of management to the observations, and the environmental effects of the management responses.

Fundamental Geographic Model

The overarching geographic model for the evolution of intertidal habitats can be simply stated as follows. The distribution, quantity, and quality of intertidal habitats depend on supplies of waster and sediment that are regulated by climate, geology, and land use, as mediated by intertidal vegetation. The more detailed models below elaborate on this fundamental model.

Intertidal landforms exist where the land meets estuarine or marine waters. Their development and natural maintenance depend on supplies of water and sediment, the former to submerge the landform, and the latter to prevent the landform from being too deeply submerged. For intertidal landforms, the limiting ingredient is sediment. There is always enough water for intertidal habitats, due to the rising level of the sea. A large supply of sediment is needed to build the landforms upward as sea level rises.

Intertidal habitats are a major component of San Francisco Bay (16, 17). The Bay occupies the lower reaches of watersheds that drain through the Golden Gate, where fluvial discharge meets the oceanic tide. The Bay is characterized by the spatial and temporal gradients of sediment transport and aqueous salinity produced by the mixing of freshwater and saltwater.

According to this definition, San Francisco Bay is actually a system of many estuaries. As a whole, the Bay is dominated by Delta throughput from the Sacramento-San Joaquin drainage. This drainage largely controls conditions in the Delta, provides most of the terrigenous sediment to the Bay, and creates the main salinity gradient between the Delta and the Gulf of the Farallones (18, 19, 20, 21). But there are many lesser, or subordinate estuaries that extend from this main gradient into local watersheds. And the comprehensive view of the Bay must include the lower reaches of all attending watersheds, as well as the receiving oceanic waters and associated outer coastline.

Most of the subordinate estuaries are downstream of the Delta. The influence of Delta throughput on the form and ecological function of the intertidal zone decreases with distance downstream from the Delta, and with distance inland within these subordinate estuaries. It can be predicted from this model that the tidal reach of each local creek includes the full compliment of hydrodynamic features of an estuary, including a aqueous salinity gradient from fresh to brackish or saline conditions, an entrapment zone or area of maximum turbidity, and stratification of flow during freshets or flood events that meet a rising tide. It follows that the larger subordinate estuaries might support ecological communities of lesser extent but similar composition to the communities of the dominant estuarine gradient between the Sacramento-San Joaquin drainage and the Gulf of the Farallones.

Geomorphic Models for the Evolution of Tidal Flats and Tidal Marshes

Tidal Flats

Tidal flats store estuarine and terrigenous sediments along their pathway between the open bays or rivers and tidal marshes. In San Francisco Bay, the structure of tidal flats consists of fine silts and clays, sand, shell hash, and an invertebrate in-fauna (22, 23). The amount of sand in tidal flats depends on their proximity to fluvial inputs or ancient sand deposits.

The distribution of tidal flats within an estuary relates directly to tidal range, salinity regime, and nearshore bathymetry (24). Tidal flats tend to be narrower under fresher conditions than under saline conditions. This is partly due to the decrease in tidal range with distance upstream within the Bay, and partly to the tendency of vascular vegetation to extend lower into the intertidal zone under fresher conditions.

Estuarine tidal flats represent a dynamic equilibrium between sediment supply and the erosive energy of the tides. They form where wave action, currents, and the duration of tidal inundation inhibit vascular plant growth (25, 26, 27), but promote the deposition of fine sediments (20, 27, 28). There are three places in a shallow estuary where this dynamic equilibrium tends to be achieved: along the foreshore (especially along the windward shore and along the largest sloughs in tidal marshes); within the brackish zones of maximum sediment entrapment (19, 29), and within the convergence zones of large sloughs subject to two or more tidal sources (30, 31, Bureau XX). It is not certain that tidal flats will naturally evolve into tidal marsh, or that the evolution from tidal flat to marsh is irreversible, even as sea level rises. Marsh plains can be swamped by rapid estuarine transgression and thusly converted into tidal flats or shallow bays.

Tidal Marshes

In the saline areas of San Francisco Bay, the upper limit of tidal marshland exceeds Mean Higher High Water (31, 32, 33). Under natural conditions, there is typically a transition zone from marshland to upland (i.e., the backshore). The backshore is indicated by changes in plant community composition across the contour of extreme tide height. The backshore is narrow where the land is steep, and broad where the uplands slope gradually to the marshland. Wind that blows salt from the estuary into the uplands and widen the backshore. The lower transition from tidal marsh to tidal flat (i.e., the foreshore) corresponds to the rather abrupt lower limit of vascular plant growth. The form and ecological nature of tidal marshes varies with tidal regime and salinity regime (6, 27, 34, 35).

Tidal marshes form when tidal flats or the backshore is colonized by vascular plants. Plant colonies decrease local wave action and currents and thus increase inorganic sedimentation. Over time, the plants contribute organic material to the sedimentary process, thus increasing the rate of upward development of the marsh through the intertidal zone. This upward development is closely followed by changes in plant community composition (27, 36, 37).

The initial formation of tidal marshland depends upon a high sediment supply and a low rate of sea level rise (38, 39, 40). Tidal marshes will not evolve if the sediment supply or the rate of sea level rise does not provide a substrate and appropriate tidal regime for plants to colonize and survive.

Under conditions of a slowly rising sea, tidal marshes tend to evolve upwards in approximate equilibrium with sea level rise (40). They can expand both downslope, due to plant colonization of the adjacent tidal flat, and upslope as sea level transgresses the land. The oldest area of a patch of tidal marsh therefore tends to be somewhere between the foreshore and the backshore.

The high-order drainage networks of large saline tidal marshes have two origins. Most of the larger channels originate on the pre-existing tidal flats. As the tidal marsh develops upward, these antecedent channels become deeper and longer (41, 42). The smaller channels of tidal marshland evolve on the marsh plain, and have no place of origin on the pre-existing tidal flat.

Intertidal Zone as Transitional Environment

Hydrological Model

The intertidal zone influences watershed outputs to the Bay. Most of the local outputs of terrigenous sediments and freshwater are transported from watersheds through the intertidal zone to shallow bays by fluvial discharge and ebb tides. Some of the sediment from local watersheds is stored within mudflats and trapped within tidal marshlands before reaching the Bay. Tidal marshes can also delay the downstream distribution of freshwater by spreading out the riverine floodwaters or by providing areas for re-circulation of freshwater between neap and spring tide series. The relative importance of watershed outputs of sediment and water therefore increases with distance away from the Golden Gate and into the local watersheds. This model applies to the tidal reaches of watersheds throughout the Bay.

Tidal marshes and tidal flats represent a net landward direction of estuarine sediment transport from the open bays. Some portion of the terrigenous sediments and the marine sediments that are mixed within the open bays is transported onto tidal flats and into tidal marshes. Daily and seasonal sequences of sediment deposition and scour produce a net landward flux of sediment across the tidal flats (43). This transport is punctuated seasonally due to re-suspension of tidal flat sediments by wind-generated waves (20, 29). A portion of the suspended sediment that reaches the marsh drainage system may wash back and forth between the marsh and the Bay, with temporary storage on the tidal flats. But most of the sediment that enters the marsh drainage system is eventually trapped within the channels or on the marsh plain.

The tidal prism of marshes helps maintain the hydraulic geometry of the larger tidal channels that connect the marshlands to the tidal flats and open bays (44, 45). The loss of tidal marshes through reclamation has therefore caused the shoaling and narrowing of these channels (46, 47). Large-scale restoration of tidal marshland would begin to reverse the historical pattern of shoaling.

The tidal and fluvial processes that affect the transitional nature of the intertidal zone vary on many time scales. Fluvial processes vary seasonally, annually, and in relation to the irregular schedules el niño or la niña climatic episodes. Tidal processes vary minute-to-minute (i.e., the velocity pulses that characterize ebb and flood flows in tidal marsh channels); hourly (i.e., on the mixed-diurnal cycle of the daily tides), bi-weekly (i.e., on the neap-spring tidal cycle); monthly, seasonally, and on longer scales of years and tens of years (6).

Chemical Model

The intertidal zone is generally regarded as a retentive environment that serves to filter throughputs of water. It also tends to retain materials that are atmospherically deposited (48). In this way, the intertidal zone serves as a filter and as a place of storage for materials that enter the zone from local watersheds or open bays. The storage function is greatly enhanced in mudflats by the filtering action of the benthic infauna, and in tidal marshes by the uptake of materials by rooted plants.

It is expected from work in other estuaries that there is no net annual output of nutrients and particulate organic matter from tidal marshland (37, 49). There may be net inputs or outputs seasonally, but on an average annual basis the inputs and outputs are roughly in balance. Tidal marshlands are also recognized to be very productive environments, owing to the high levels of primary production by vascular plants on the marsh plain, algae on the exposed tidal flats and channel banks, and phyto-plankton in the channel waters. While most of this production fuels endogenic processes, the production is so great that there may be some seasonal leakage downstream or bayward. Most of the output from the intertidal zone occurs in autumn and winter, during the period of maximum decay of detritus and aerial portions of marsh plants (50). Tidal marshes can be either a source or a sink for carbon, depending on the relationship between aerobic microbes and their consumers (51).

Under special circumstances, the intertidal zone may yield sediment and contaminants. Tidal flats and the foreshore can erode due to increased water supply (i.e., increased sea level and/or increased wave energy), decreased sediment supply, or both. Sequential wetting and drying of shallow water sediments may promote the release of contaminants in soluble forms, depending upon the concentration of the contaminants in the sediments, the size of the organic soil faction, and exposure of the contaminants to export processes. The small channels of tidal marshes are dynamic features that are continuously cutting headward or retreating (30, 31), and thus both exhuming and storing sediment. In this regard it should be remembered that the small channels comprise most of the flux boundary between the land and the water.

Ecological Model

The movements of plants and animals in and out of intertidal habitats represent important ecological linkages between these habitats and adjacent environments. Upland wildlife frequently commutes to and from tidal marshes to feed. Mammals and birds that are mainly residents of tidal marshes use the adjacent uplands to escape tidal flooding (65). Some fishes spend their lives in tidal marsh channels, but other fishes follow the tide in and out of marsh channels from adjacent bays and rivers (56).

Geomorphic Model for Tidal Flat and Tidal Marsh Development

Plan Form

Tidal marshes and stable tidal flats consist of channels large and small in well-organized drainage networks, and broad plains of low relief between the channels. Mature tidal marshes contain shallow ponds or pannes on the low-gradient plains.

The drainage networks of tidal flats and marshes are typically dendritic and fractal in plan view (30, 52). The termini of first-order channels delineate the headward reaches of a drainage network. These are the narrowest channels that do not branch. Two or more first-order channels that come together form a second-order network; two or more second-order channels that come together form a third-order network, and so forth.

The amount of meander of tidal marsh channels varies with marsh elevation (or age) and slope of the marsh plain. The most sinuous channels and most complex drainage networks are maintained in higher marshes with less slope. Lower marshes with steeper slopes have less sinuous channels in parallel drainage networks that are mostly perpendicular to the foreshore.

Channel density varies with salinity regime, as mediated by the vertical extent of vascular plant growth in the intertidal zone. The tendency of vegetation to grow lower in the intertidal zone under fresher conditions extends the marsh plain bayward (narrows the tidal flats), and therefore also moves the tidal source further from the marsh interior. As a result, the tidal marsh channels tend to shorten in their headward reaches. Freshwater tidal marshes have simpler and shorter drain age system with broader plains between channels than saline marshes (35).

The average form of tidal flats and marshes in plan view varies slowly over time. Long-term changes in the distribution of tidal flats may signal a major change in local or regional supplies of suspended sediment (53). Cross-sections of the foreshore in many parts of the Bay reveal alternating strata of mudflat and marsh sediments, indicating alternating periods of foreshore advance and retreat (i.e., horizontal accretion and erosion). Changes in channel density or meander geometry of mature tidal marsh drainage networks depend on changes in plant vigor or plant community composition, and can signal a local or regional change in water supply (i.e., sea level) and salinity regime. Large seasonal variations around the average conditions have been noted, however. For example, the elevation and bayward extent of tidal flats varies seasonally with sediment supply, with winter and spring gains being offset by summer and fall losses (54). The width of the channel side plant zone in brackish marshes can be twice as wide in wet years of low salinity than in dry years of high salinity (27).

Cross-sectional Form

Plants and wildlife show vertical zonation within the intertidal zone. The zonation is due to complex interaction among biotic and abiotic influences (6, 27, 55). These interactions vary among species and life stages. While the mechanisms of zonation are not well known for many species, the patterns of zonation correlate strongly with tidal elevation, distance from tidal source (i.e., distance upstream along tidal marsh channels or distance away from the channel banks), and aqueous salinity regime.

The cross-sectional form and dimensions of natural tidal channels can be predicted based upon headward tidal prism, tidal range, and salinity regime. With decreasing tidal range and increasing freshwater influences, the width-to-depth ratio of tidal channels tends to increase. For any tidal marsh or tidal flat, channel cross-sectional area and depth decrease headward (56, 57).

Natural levees only attend the downstream reaches of the largest channels in tidal marshes (31) and along tidal reaches of local rivers and streams. The distribution of natural levees in tidal marsh systems is explained in part by the greater supply of suspended sediment and vertical mixing of the flood tide waters in the downstream reaches of the drainage networks (56). Natural levees are common features along major channels leading from the foreshore into mudflats. These levees are apparently created by the deposition of larger sediments near the channel bank during flood tide.

Large tidal marsh channels have internal berms created by slump blocks produced by bank undercutting. Slumps occur on the outside of meander bends and on both sides of strait reaches. Large supplies of suspended sediment and its entrapment by vegetation on the slump blocks can cause them to evolve upward faster than they can be eroded, such that banks rebuild themselves in place rather migrate across the marsh plain (30, 31). Smaller channels that evolve on the marsh surface are more dynamic, variously retrogressing bayward due to plant capture in their headward reaches, or elongating headward to accommodate local increases in tidal prism (30, 31).

The relative influence of abiotic tidal influences decrease with intertidal elevation, while the relative influences of non-tidal biotic processes increase. At the lower limits of the tides, the structure of habitats is mainly controlled by the direct tidal action, especially through deposition or scour of inorganic sediment. At the higher limits of the tides, habitat structure is mainly controlled by vascular plant growth, especially the development of peaty soils. The geomorphic work of the tides and plant growth are approximately co-equal near the Mean High Tide datum.

This cross-sectional model and the plan form model (see above) comprise a three-dimensional model of tidal marsh form. The model predicts that elevation and the geomorphic influences of biotic processes in a tidal marsh increase together with distance away from a tidal source, such as the mouth or bank of a tidal channel. Based upon this model, it might be predicted that the effects of filter feeders on suspended sediment supply decrease with tidal elevation, that the organic faction of tidal marsh sediments increases with elevation, and that the formation of pannes of tidal marsh drainage divides is mainly controlled by biotic processes. It also suggests that the dynamics of the headward reaches of the first-order tidal channels is due to their spatial correspondence to the co-equal give-and-take of the erosive actions of the tides and constructive actions of plants near the MHW datum.

Ecological Model

Temporal Variability of Plant and Animal Communities

Patches of intertidal habitat support resident populations of non-native as well as native plants and animals, plus populations of migratory and transient species (66). Native species comprise most of the vascular flora (65), although non-native species can dominate the aerial extent of the vascular plant community at some locales, especially along the foreshore and backshore. The temporary use of intertidal habitats by transient or migratory wildlife may relate to their breeding or rearing, foraging or refuge, or resting (66). For some animal species, especially aquatic insects (67, 68, 69), anadromous fishes (70, 71), and migratory waterfowl (72), the use of intertidal channels is restricted to certain life stages or seasons. Some species of estuarine fishes (73) and shorebirds (64) only use tidal marshes during high tides. Changes in the local or regional mosaic of intertidal and adjacent habitats can either disrupt or enhance their support of wildlife, depending upon habitat patch size, shape, the distance between patches of like kind, and the mix of habitat types (74). Terrestrial predators, including feral dogs and non-native fox that occasionally target tidal marshes can significantly affect the distribution and abundance of native animals, especially resident birds and small mammals (65).

For any salinity regime, the species composition of intertidal communities changes over time as the landforms evolve upward from tidal flats to high marsh. Except for truly freshwater tidal marshes, soil salinity and the abundance of salt-tolerant plants generally increase as habitats gain elevation and age (40).

At any elevation within the intertidal zone, the species composition of plant and animal communities varies over time due to such things as invasions, changes in salinity (32), changes in tidal hydroperiod (6), and disturbance by people. Drought and deluge can affect significant increases and decreases in salinity, with concomitant shifts in species abundance (32, 75).

Intertidal Zonation

Variations in plant community composition are strongly correlated to variations in aqueous salinity regime along the main axis San Francisco Bay and along its tributaries (75, 32). Although many factors may underlie this correlation (75, 6), soil salinity is apparently an important causative agent (27, 76, 77, 81, 82, 83, 84). At any point along the estuarine gradient, plant community composition varies with elevation and distance from tidal source (i.e., distance away from the foreshore or distance from channel banks) (80, 81), which are proxies for tidal hydroperiod and soil salinity (6, 27, 77, 84). The fresh, brackish, and saline zones of San Francisco Bay, and the low, mid and high marsh zones within a tidal marsh are defined by their indicative plant assemblages. These zones expand and contract due to variations in freshwater supplies that control soil salinity within and between marshes. Abundant freshwater inflows through the Delta can push the brackish zone of the estuary downstream, and can cause the channel-side vegetation within tidal marshes to expand onto the marsh plains (27).

<u>Integrated Tidal Marsh and Tidal Flat Ecology and Geomorphology</u>

Intertidal habitats tend toward an average form in dynamic equilibrium with local or regional changes in sediment and water supplies, as affected by climate, geology, and land use. They are highly organized landscapes with well-defined physiographic features that are predictably distributed through space and over time.

The relative geomorphic importance of abiotic and biotic processes varies with elevation and distance from tidal sources in the intertidal zone. Biotic processes, such as production of peats and vegetative reproduction, increase with tidal elevation, distance upstream within drainage networks, and distance away from channel banks. Abiotic and biotic controls fluctuate in dominance within small channels that dewater at low tide. Weak tides above Mean High Water tend to permit channel capture by vascular vegetation, resulting in channel retrogression. But in large tidal marshes, there tends to be a compensatory relationship between natural losses and gains in the total length of all small channels. Individual retrogression events are incompetent to affect the cross-sectional area of the much larger channel system at its tidal source. Therefore, the system is subject to the same tidal prism before and after individual retrogression events. The tidal prism displaced from retrogressing channels moves headward along the hydraulic gradient generated by channel friction to other channels that consequently elongate, such that the overall tidal prism and amount of channels large and small are conserved. The hydraulic gradient is slight, and a large system is required to generate sufficient hydraulic head to move enough water headward to cause channel elongation. Lesser systems tend to experience chronic retrogression, with overall loss of channel capacity and ecological function over time.

Restricting the tidal source or moving it away from the interior reaches of the system promotes retrogression, expansion of areas that lack channels (i.e., loss of habitat for estuarine fishes and other aquatic resources), and expansion of natural ponds or pannes on drainage divides (i.e., gain in habitat for shorebirds and waterfowl). Increasing the tidal source or moving it more interior promotes headward channel erosion and loss of ponds.

Vascular vegetation plays a critically important ecological role because it affects the physical structure of habitats and because it functions as a food resource throughout most of the intertidal zone.

Tidal marshes are where the estuary and the uplands meet. The intersection is not fixed in time or space because marsh elevations are constantly changing, relative to estuarine water heights. The intersection is always between the foreshore and backshore, however, and may be more narrowly delineated. Conditions above MHW and below MTL seem to be more terrestrial than estuarine, and more estuarine than terrestrial, respectively (6, 78). In small channels of saline marshes that have base elevations above MTL, tidal velocities tend to be too weak to prevent channel capture by marsh plants (30). Elevation boundaries between plant assemblages tend to correspond to local MHW (78). Tidal marshes seem to support three nearly independent food webs, one for large tidal marsh channels, one for the marsh plain and backshore, and one for small channels (79). The latter food web might provide a weak link between the other two. Detritus is expected to be an important source of energy at elevations above MHW, but is largely replaced by attached and epiphytic algae at lower elevations (58). Beds of filter-feeding bivalves are also expected to strongly influence suspended sediment supplies for tidal flats and large tidal marsh channels. Based on this evidence, the actual boundary between bays and uplands in tidal marshes seems to trace the beds of small channels, between MTL and MHW.

The conservation of native biological diversity of the intertidal zone depends on the natural, or naturalistic variability of the tides, freshwater supply, sediment supply, and salinity regime (75, 80).

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APPENDIX C

Survey of Factors, Parameters, and Methods Used in Other Monitoring Projects and Programs

Summary Findings

Twenty-nine project monitoring plans or reports and four monitoring program plans were screened for further review and summary. All the projects are located in the San Francisco Estuary, and most are located in North Bay and the Delta. One of the program plans pertains to Suisun Marsh in the Estuary, and the other three program plans pertain New York, Great Lakes, and Louisiana. Of the four program plans, those for Suisun and Louisiana were reviewed in detail because they are relatively comprehensive and they pertain explicitly to estuarine marshlands. Of the twenty-nine documents that pertain to projects, fifteen contain enough detail about factors and methods to warrant their further review. The fifteen project documents represent twelve different projects, most of which exist in North Bay.

The review of selected plans and reports is organized in four parts. Matrix A1 shows the parameters chosen for each factor of each project, and matrix A2 shows the factors and their parameters for the two programs. Matrices B1 and B2 show the methods for each parameter of each project and program, respectively.

As explained in the supporting text for the Pressure-State-Response (PSR) conceptual model for the WRMP (see Generalized Conceptual Model Document), any of the parameters could be either pressure or state indicators, depending whether they are response or causal agents. For example, vegetative cover or plant stem density could be state indicators for plant community condition, and pressure indicators for small mammals that use the vegetation as habitat. The matrices therefore do not include any designation of parameters as either pressure or state indicators.

The matrices simply summarize the factors, parameters, and methods as reported in the selected documents. There is no assessment of the correctness or completeness of the monitoring efforts. The following summary statements are supported by the matrices and related documents.

Factors and Parameters of Programs

1. The selection of factors and parameters to monitor depends on the goals and objectives of the project or program.

2. Regional monitoring programs address more factors with more parameters than efforts to monitor projects.

3. The two primary goals of monitoring programs are to standardize efforts to monitor projects and to assess overall regional condition and trends.

4. Regional monitoring programs rely upon local science to support methodologies, even for methods that are comparable between regions.

5. Regional monitoring programs rely on large data management systems to achieve standardization and coordination among local projects.

6. Regional monitoring programs rely on regular outside technical review to maintain the state of science and technology within the programs.

Factors and Parameters of Projects

7. For most projects, there are no explicit conceptual models to justify the factors or parameter to monitor. Reports about projects usually do not specify the frequency (spatial or temporal) of samples, sample size, or the periodicity of statistical summaries.

8. For projects, the plant community, special status species, the fish community, the bird community, and physical marsh development are common major factors. Water quality is not as common as a major factor.

9. Most efforts to monitor projects are conducted by private consultants and they only address factors that the project sponsors or clients pay for. For example, information about neighboring projects is not included unless requested by the project sponsor, even if the neighboring project could have significant influence on the performance of the subject project.

Methods

10. Reports about projects seldom indicate the “representativeness” of the data. That is, they seldom explicitly state whether the data pertain to the entire project site or some stratum of the site, for all seasons of a year or for part of a year.

11. Most reports about projects do not indicate how the monitoring data will be analyzed or how the findings will be presented.

12. Most efforts to monitor projects involve surveying elevations, either relative to a tidal datum or to an arbitrary site-specific datum. There is seldom any report on the integrity of benchmarks, the error of the survey, or the tolerances of survey instruments.

13. For most projects, the sampling interval for most parameters is not adjusted for changing rates of processes. Fixed intervals of sampling are used for parameters with evolving rates of change. For example, plant communities are sampled seasonally each year even if the community is expected to change more rapidly in the first few years than in later years.

14. Most methods involve non-random selection of permanent sampling stations, such as monumented cross-sections, vegetation transects, plots, or census tracks. The second most common approach is random selection of fixed stations. Whether or

not the analyses address potential problems with autocorrelation of time series data is not known.

15. Fish monitoring usually features species composition and size class analysis based on a variety of gear types depending on field conditions. It is clearly difficult to sample fish in tidal marshes.

16. Plant sampling usually features percent cover by species based on point-intersect methods or square plots along fixed transects.

17. Small mammal sampling usually features trap grids at fixed locations.

18. Bird sampling usually features relative abundance of species based on counts at fixed stations or census tracks.

19. Measures of physical processes usually features tide height without datum control.

20. Because of the variation in method and technique among projects, only the most rudimentary kinds of information can be gleaned commonly from all the reports as a collective body of work. The only data about physical condition that are common to all projects are elevations without datum control, and the only common biological data are for species richness and species composition. It is not clear in most project reports how to interpret the absence of a species

Matrix A: Ecological Factors and Parameters

Part A1: Example Wetland Projects

Project Name and (Reference #)	**Factor**	**Parameter**
Eden Landing (1)	Waterbirds	Use and distribution
	Special Status Specie	Salt marsh harvest mouse, California clapper rail, snowy plover
	Plant Community	Total plant cover; Plant species composition; Percent native species; Average and maximum plant height; alt marsh harvest mouse habitat structure
	Plant Colonization	Plant patch size, patch location, patch species composition
	Marsh Development	Channel distribution, location, geometry, sedimentation
San Joaquin River Riparian and Flood Plain Restoration (2)	Vernal Pool Community	Aquatic vertebrate and macro-invertebrate species composition
	Fish Community	Fish species composition
	Amphibian and Reptile Community and Terrestrial Habitat Association	Herpetofauna species composition

Part A1 (cont'd)

Project Name and (Reference #)	**Factor**	**Parameter**
San Joaquin River Riparian and Flood Plain Restoration (cont'd)	Special Status Species	Tadpole shrimp, fairy shrimp, giant garter snake, yellow-billed cuckoo, Aleutian Canada goose, wood duck, sandhill crane
	Bird Community	Neo-tropical migratory and resident songbird species abundance and composition
	Mammal Community	Mammal species composition
Sonoma Baylands (3, 4)	Water Quality	Salinity, temperature, dissolved oxygen,
	Marsh Development	Channel geometry, tidal hydrology, sedimentation
	Bird Community	Species composition, species abundance, habitat use patterns
	Special Status Species	California clapper rail, California black rail
	Benthic Community	Taxonomic composition, density, total density, biomass, species diversity
	Plant Community and Plant Colonization	Presence/absence, total percent cover, species distribution
Cullinan and Tolay (5, 6)	Marsh Development	Tidal hydrology, sedimentation, channel distribution and geometry, habitat acreage
	Water Quality	Total hardness, temperature, pH, turbidity, salinity, and DO
	Benthic Community	Taxonomic composition, density, total biomass
	Plant Community	Species composition, stem density, plant height, percent cover per species
	Fish Community	Species composition, size distribution per taxa, gut content
	Bird Community	Species composition, density for common species
	Mammal Community	Species composition, relative abundance, density
Napa River Flood Protection (7,8)	Marsh Development	Tidal hydrology, channel cross sections, sedimentation, bank stability, vegetation roughness
	Plant Community and Plant Colonization	Species composition, percent cover per species, stem density, natural recruitment, percent cover of non-native species, total biomass, tree health and tree stature
Petaluma City Wastewater Marsh (9)	Wildlife Use	Presence/absence, avian diseases, mosquito production, habitat quality

Part A1 (cont'd)

Project Name and (Reference #)	**Factor**	**Parameter**
Petaluma City Wastewater Marsh (cont'd) (9)	Marsh Development	Tidal hydrology, channel geometry, sedimentation
	Plant Community	Percent cover per species, vigor of selected species
	Water Quality	DO, pH, temperature, turbidity, total coliform, fecal coliform, visible oil, objectionable algae and odors, total and dissolved sulfides, TSS, specific conductance, ammonia and unionized ammonia, Chlorophyll *a*, silica, aquatic toxicity, nitrate + nitrite, total phosphorus, trace metals, organic compounds, salinity
Petaluma Marsh Expansion (10)	Sedimentation	Sedimentation rate
	Marsh Development	Habitat types, habitat locations, habitat amounts, channel geometry
	Tidal Hydrology	Tidal datums, tidal regime
	Water Quality	Conductivity (salinity), nutrient concentrations, temperature, pH, dissolved oxygen, turbidity
	Macroinvertebrate Community	Taxonomic composition and biomass of benthos and insects
	Fish Community	Species composition and size distribution
	Plant Community	Species composition, relative abundance, percent cover by species, height distribution
	Bird Community	Species composition, habitat use patterns
Ora Loma (11, 12, 13)	Marsh development	Channel geometry
	Sedimentation	Sedimentation rate
	Tidal Hydrology	Tidal elevations, tidal regime
	Plant Community	Species composition, relative abundance, percent cover by species, percent total cover
	Bird Community	Species composition, habitat use patterns

Matrix A: Ecological Factors and Parameters

Part A2: Example Wetland Monitoring Programs

Program Name and (Reference #)	**Factor**	**Parameter**
Suisun Marsh Monitoring Program (14)	Channel Water	Salinity, tide stage
	Edaphic Condition	Soil salinity
	Pond Water	Pond salinity, Ph, hydroperiod, discharge salinity
	Plant Community	Species distribution and abundance, production by target species, quantity of salt marsh harvest mouse habitat
	Special Status Species	Salt marsh harvest mouse, *Neomysis*, *Acanthomysis*, striped bass, Chinook salmon, delta smelt, longfin smelt, splittail, shimofuri goby, Asian clam
	Aquatic Resources	Fish abundance and diversity
CWPPRA Project Monitoring Program (15)	Habitat Mapping	Project boundaries, habitat patch metrics and spatial distribution
	Meteorology	Precipitation, wind speed and direction
	Hydrology	Surface water levels, groundwater levels, surface water salinity and temperature, discharge, suspended sediment, bathymetry
	Edaphic Conditions	Bulk density, total organic matter, percent water, soil salinity, groundwater salinity, soil sulfide, grain size, soil redox
	Sedimentation	Average marsh elevation, vertical accretion rate,
	Subsidence	Subsidence rate
	Marsh erosion and soil creation	Vertical soil profile, average marsh elevation, vertical erosion, horizontal erosion
	Plant Community	Species composition, relative abundance, biomass
	Herbivory	Herbivory rate
	Fish Community	Species composition, species richness, density, size distribution, biomass
	Water Quality	Trace metals, PCBs, pesticides, PAHs, TOC, nutrients

Matrix B: Parameters and Methods

Part B1: Example Wetland Projects

Project Name and (Reference #)	Parameter	Methods	
		Technique	Frequency
Eden Landing (1)	Waterbird use and distribution	Qualitative surveys of abundance, presence/absence, and habitat associations	Monthly each year for years 1-5; Monthly every 5th year for years 5-20
	Salt marsh harvest mouse	Qualitative searches and trapping grids	Annually during maximum tide and breeding season every 5th year for years 1-20
	California clapper rail	Qualitative surveys and quantitative listening stations to map territories	Annually during maximum tide and breeding season every 5th year for years 1-20
	Snowy Plover	Quantitative CDFG protocol for nesting surveys (Casady 1998); qualitative surveys of hatching success and predation,	Weekly from February-August (unspecified number of years)
	Total plant cover; Plant species composition; Percent native species; Average and maximum plant height	Quantitative point-intercept along three or more replicate transects 30-m long	Annually at 1-m intervals along transects (unspecified number of years)
	Salt marsh harvest mouse habitat structure	Qualitative surveys of pickleweed structure and vigor	NA
	Plant patch size, Plant patch location, Plant patch species composition	Quantitative mapping from aerial photo scale 1:4800 with ground-truthing and photo stations	NA
	Channel distribution, Channel location, Channel cross section	Quantitative mapping from aerial photo scale 1:4800 with ground-truthing and photo stations plus monumented cross sections (no report of survey errors)	NA
	Sedimentation rate	Independent staff gauges	NA

Part B1: Example Wetland Projects

Project Name and (Reference #)	**Parameter**	**Methods**	
		Technique	**Frequency**
San Joaquin River Riparian and Flood Plain Restoration (2)	Aquatic vertebrate and macro-invertebrate species composition	Qualitative surveys of pools using "D" frame dip nets and 1-in mesh beach seines for presence/absence	Annually during aquatic phase of pools
	Fish species composition	Qualitative beach seining parallel to shore using 3-mm mesh nets	Weekly from February – April for 3 years, daily from April-June for 1 year
	Tadpole Shrimp, Fairy Shrimp	Qualitative surveys of pools using "D" frame dip nets and 1-in mesh beach seines for presence/absence	Annually during aquatic phase of pools
	Herpetofauna species composition and terrestrial habitat association	Qualitative drift fences, Sherman live traps, and nighttime spotlight searches in different habitat types	Semi-weekly late July to late October; 2 triad systems of 15-m drift fences per habitat type with 5-gal pitfall traps at fence ends and intersections and 12 Sherman live traps along the fences; spotlight surveys one night during each trap period
	Yellow-billed Cuckoo	Qualitative surveys using song playbacks	5-min long playbacks every 200 m along 6 riparian transects of varying length twice per year during summer morning hours
	Aleutian Canada Goose	Survival rate and quantitative population estimates based on ratios of marked to unmarked individuals seen through spotting scopes, plus counts of individuals during fly-ins to roosting areas.	200 geese are marked annually; direct counts are made daily during fall migration; marked-unmarked counts are made semi-weekly during fall migration

Part B1: Example Wetland Projects

Project Name and (Reference #)	**Parameter**	**Methods**	
		Technique	**Frequency**
San Joaquin River Riparian and Flood Plain Restoration (cont'd) (2)	Sandhill Crane	Qualitative surveys of abundance at known forging and roosting areas	Monthly during morning hours from late September to early December
	Wood Duck	Qualitative records of occupancy and number of eggs and young in non-random artificial nesting boxes	Semi-monthly observations of 10 nesting boxes from mid-March to mid-August
	Sandhill Crane	Qualitative surveys of abundance at known forging and roosting areas	Monthly during morning hours from late September to early December
	Sandhill Crane	Qualitative surveys of abundance at known forging and roosting areas	Monthly during morning hours from late September to early December
	Giant Garter Snake	Qualitative surveys of abundance using modified minnow traps at areas of suitable habitat	80 traps placed 15 m apart along one transect at each of two shorelines for 16 consecutive days in summer.
	Mammal species composition	Qualitative drift fences, Sherman live traps, and nighttime spotlight searches in different habitat types	Semi-weekly late July to late October; 2 triad systems of 15-m drift fences per habitat type with 5-gal pitfall traps at fence ends and intersections and 12 Sherman live traps along the fences; spotlight surveys one night during each trap period

Part B1: Example Wetland Projects

Project Name and (Reference #)	Parameter	Methods	
		Technique	Frequency
San Joaquin River Riparian and Flood Plain Restoration (cont'd) (2)	Neo-tropical migratory and resident songbird species abundance and composition	Quantitative point counts in closed habitat and transect counts in open habitat, plus qualitative constant effort mist netting in closed and open habitats	Annual point counts (2 random 5-min, 100-m fixed radius stations) and transect counts (2 transects 200-m wide and 150-m long) in each of 10 habitat types in mid summer; 11 mist nets operated for 5 early morning hours during fall migration
Sonoma Baylands (3, 4)	Salinity, temperature, and dissolved oxygen	Meters used to field-test non-random water samples from monumented stations, plus qualitative records of weather and other field conditions at sample time	Semi-monthly readings from 0.5 m depth during slack high tide at 8 monumented stations
	Channel geometry	Monumented cross sections and longitudinal profile tied to NGVD based on local benchmarks, plus monumented photo stations at each cross section No report of survey errors	Occasional resurveys of 16 cross sections and 1 longitudinal profile as needed to show change
	Tidal hydrology	Submersible pressure transducer for continuous record of water surface relative to NGVD 29 with calibration to observed staff gauges.	Monthly downloading of nearly continuous readings from data loggers for 6 non-random tide stations

Part B1: Example Wetland Projects

Project Name and (Reference #)	Parameter	Methods	
		Technique	Frequency
Sonoma Baylands (cont'd) (3, 4)	Sediment density and Sediment surface elevation	Resistivity probes to show vertical density profiles and estimate surface elevation relative to NGVD 29 in newly deposited sediment Transects tied to measure elevation of mudflats and levees relative to NGVD 29	Monthly readings at 21 non-random probe installations Semi-annual resurveys of 6 non-random transects of varying length
	Bird species abundance, composition, and habitat use patterns	Qualitative counts of individuals of each species and observations of bird use from monumented census stations for each habitat type	Seasonal surveys from 10 non-random monumented stations timed with expected periods of peak bird use at the site during various tidal stages
	California clapper rail and California Black Rail	USFWS protocol	One breeding season survey so far
	Benthic invertebrate taxonomic composition, density per taxa, total density, standing stock, species diversity	Quantitative counts of individuals per taxon from standardized sediment core samples	Spring and fall collection of 6 random 5-cm to 7-cm diameter cores 20 cm deep at each of 3 non-random water quality stations
	Plant species presence/absence, percent cover, species distribution	Quantitative counts of occurrence of species along transects and qualitative ground-based site reconnaissance	Annual surveys along 6 non-random transects of varying length and overall site reconnaissance during peak growth period

Part B1: Example Wetland Projects

Project Name and (Reference #)	Parameter	Methods	
		Technique	Frequency
Cullinan and Tolay (5, 6)	Tidal hydrology	Continuous records of water level and flow using recorders with data loggers (types not specified)	Monthly or seasonal summaries of water level records at 5 (Tolay) and-15 (Cullinan) non-random stations
	Sedimentation,	Sedimentation pins and GPS surveys of relative elevation change	Seasonal measurements at 12 (Tolay) and 60 (Cullinan) non-random sedimentation pins and annual ground surveys (distribution not specified)
	Channel distribution and habitat acreage	GIS analysis of aerial photography	Frequency and scale of aerial photos not specified
	Total hardness, temperature, pH, turbidity, salinity, and dissolved oxygen	Meters used to measure depth-integrated water samples	Semi-annual measurements of one high tide sample from each 250 sq m plot having a slough
	Macroinvertebrate taxonomic composition, density per benthic taxon, total biomass of benthos	Quantitative core sampling for benthos and qualitative sweep netting for insects along transects and within plots	1 or more annual cores (10-cm d and 10-cm deep) and 3 sweep net passes within 0.5 sq m plots along transects at Tolay (spatial frequency and distribution not specified) or within 500 sq m plots at Cullinan
	Mammal species composition, relative abundance, density per species	Quantitative counts and mark-recapture analyses based on grids of Sherman live traps at stations (Cullinan) or along transects (Tolay)	Annual trapping for 3 days per grid (size, number, and distribution of grids not specified)

Part B1: Example Wetland Projects

Project Name and (Reference #)	Parameter	Methods	
		Technique	Frequency
Cullinan and Tolay (cont'd) (5, 6)	Plant species composition, stem density, plant height, percent cover per species	Quantitative counts and measurements within plots along transects across sites, plus quantitative maps of plant patches based on aerial photography	Seasonal measurements within 0.5 sq m plots at 5-m intervals along 1 15-m long transect at each of two sites (frequency and scale of aerial topography not specified)
	Fish species composition, relative abundance, size or age distribution per taxa, gut content	Qualitative counts based on multiple gear types (throw nets, variable-mesh gill nets, bag seines) used in plots or along transects	Annual for years 1-3 and hence every two years (frequency and distribution of transects or plots not specified)
	Bird species composition, density per common species	Quantitative visual counts augmented by call playback surveys in variable circular plots, plus aerial surveys	Seasonal (years 1-3), annual (years 4-10, and hence every 5 years) surveys during 3 early morning hours (frequency and distribution of plots and aerial surveys not specified).
Napa River Flood Protection (7, 8)	Tidal hydrology	Water level and flow recorders with data loggers (types not specified), plus peak stage recorders and field surveys of high water marks with reference to NGVD 29 to calibrate a site-specific numerical model	15-min interval measurements of water level and flow at 2-3 recording gauges; 5 non-random peak stage gauges and field surveys for floods above 20,000 csf
	Channel cross sections	Monumented transects where erosion or sedimentation is expected	22 non-random transects surveyed every 2-4 years and once after each flood exceeding local 5-yr recurrence interval

Part B1: Example Wetland Projects

Project Name and (Reference #)	**Parameter**	**Methods**	
		Technique	**Frequency**
Napa River Flood Protection (7, 8) (cont'd)	Sedimentation	Monumented cross sections for channels (see above); staff gauges and settling plates for terraces and marsh plains	Annual or biannual measures of deposition at 22 plates or gauges located at regular intervals between channel cross sections
	Bank stability	Monumented cross sections, erosion pins, qualitative plant cover estimates, and interpretation of bank plan form using geo-rectified natural color aerial photos	Annual surveys of 14 non-random cross sections plus erosion pins between the cross sections; annual aerial photography scale 1:4,800 at low tide
	Edaphic condition	Soil salinity in non-random quadrats	Annual (years 1-5) and every 5th year (year 6-40) during peak growth period
	Vegetation roughness (hydraulic roughness caused by plants)	Qualitative estimates of density of plant cover within 3 ft of flood plain or terrace ground surface	Annual surveys (number and location of surveys not specified).
	Habitat amount and distribution	Quantitative mapping of habitat patches using ground-truthed geo-rectified natural color aerial photos	Annual aerial photography of scale 1:4,800 taken at low tide and truthed with 1 or more non-random monumented transects per major habitat type
	Plant species composition, percent cover, percent non-native species, plant stem density, total biomass	Quantitative point-intercept counts of individuals and percent cover per species and age-class along non-random transects in each major habitat type	Annual (years 1-5) and every 5th year (year 6-40) during peak growth period

Part B1: Example Wetland Projects

Project Name and (Reference #)	Parameter	Methods	
		Technique	Frequency
Napa River Flood Protection (7, 8) (cont'd)	Tree health, tree stature, and natural recruitment	Quantitative measures of tree height and basal area, plus qualitative visual inspection of foliage health along non-random transects through tree plantings; quantitative counts of seedlings in random 1sq m plots	Annual (years 1-5) and every 5th year (year 6-40) during peak growth period along 4 transects for each major habitat type
Petaluma City Waste Water Marsh (9)	Tidal hydrology and sedimentation	Point measurements of water depth during approximate slack Mean High Water at random plots in major habitat types, plus monumented non-random photo stations	Annual photos at 12 stations and annual measurements in 5 or more random 0.5-m quadrats along each of 2 non-random transects (length and distribution of transects not specified)
	Channel geometry	Monumented cross sections	Annual measurements (number and distribution of cross sections not specified)
Petaluma City Waste Water Marsh (cont'd) (9)	Percent cover per plant species, plant species composition, percent non-native species	Quantitative counts of species using point intercept in quadrats along non-random transects in each major habitat type, plus photo documentation of quadrats and at non-random photo stations	Annual photos at 12 stations; annual counts in 5 or more random 0.5-m quadrats along each of 2 non-random transects (length and distribution of transects not specified)
	Wildlife presence/absence	Qualitative notation of tracks, sightings, and other signs	Occasional as aspect of other field work
	Wildlife habitat suitability	Quantitative index of quality for major habitat types based on the field surveys of plant, hydrology, and contaminants	Once before and once after project construction

Part B1: Example Wetland Projects

Project Name and (Reference #)	Parameter	Methods	
		Technique	Frequency
Petaluma City Waste Water Marsh (cont'd) (9)	Mosquito production	Quantitative and qualitative field surveys to locate breeding sites and to estimate larval density and production	Occasional surveys during breeding season each year
	Avian diseases	Qualitative surveys to detect unusual bird behavior or deaths	Occasional surveys during the conduct of other monitoring
	Dissolved oxygen, pH, temperature, salinity, specific conductance	In situ meters used for depth-integrated measurements in fixed non-random stations in each major habitat type	Weekly in summer and monthly in winter at 0.5-m depth increments (number of stations not specified)
	Turbidity	In situ measures of light transmission at fixed depth on flood and ebb tides and pond outfalls (type of instrument not specified)	Weekly in summer and monthly in winter (number and distribution of instruments not specified)
	Visible oil, objectionable algae and odors	Qualitative surveys in each major habitat type	Occasional during the conduct of other monitoring
	Total and dissolved sulfides, TSS, specific conductance, ammonia and unionized ammonia	Laboratory analyses of surface water grabs standardized b y time of day and stage of tide	Monthly at each pond or panne (number of stations not specified)
	Chlorophyll *a*, silica	Laboratory analyses of surface water grabs standardized by time of day and stage of tide	Monthly during summer at each pond or panne (number of stations not specified)
	Total coliform, fecal coliform,	Laboratory analyses of surface water grabs standardized by time of day and stage of tide	Occasionally as needed; daily during incidences of avian disease
	Aquatic toxicity	96-hr LD_{50} of two test species in flow-through chamber with composite water from all ponds receiving wastewater (test species not specified)	Quarterly each year (number and distribution of water grabs for each composite sample not specified)

Part B1: Example Wetland Projects

Project Name and (Reference #)	Parameter	Methods	
		Technique	Frequency
Petaluma City Waste Water Marsh (cont'd) (9)	Total phosphorus, nitrate and nitrite	Laboratory analyses of surface water grabs standardized by time of day and stage of tide	Monthly from May to September in years 1, 3, 5 (number of stations not specified)
	Trace metals, organic compounds	Laboratory analyses of surface water grabs standardized by time of day and stage of tide	Quarterly in years 1, 3, 5 for inflow and outflow of ponds receiving wastewater
	Salinity	Refractometer reading of surface water during slack high tide in ponds and tidal channels	Monthly during years 1, 3, 5 (number of stations not specified)
	Tissue contamination and bio accumulation	Laboratory analyses of concentrations of trace metals in fish tissue, bird eggs and bivalves taken from ponds and marsh	Annual collection of 30 g or more of tissue from 2 composite random samples of 5 or more individual fish, eggs and bivalves of target species
Petaluma Marsh Expansion (10)	Sedimentation rate	Quantitative measurement of at non-random sedimentation pins	Annual (number and location of pins not specified)
	Habitat types, habitat locations, habitat amounts	Quantitative maps based on geo-rectified natural color aerial photos	Annual photos at scale 1:4,800 timed at low tide
	Channel geometry	Measurement of channel density based on geo-rectified aerial photos, plus monumented non-random cross sections	Annual photos at scale 1:4,800 in years 1, 3, 5, 7, and 10 timed at low tide; cross sections surveyed annually (number and distribution of cross section not specified)
	Conductivity (salinity), nutrient concentrations, temperature, pH, dissolved oxygen, turbidity	Depth-integrated measurements with in-situ instruments at non-random stations on selected tidal sloughs (instrument types not specified)	Semi-annual during spring and autumn at high tide (number of stations not specified)

Part B1: Example Wetland Projects

Project Name and (Reference #)	Parameter	Methods	
		Technique	Frequency
Petaluma Marsh Expansion (cont'd) (10)	Tidal datums, tidal regime	Continuous in situ water level and flow recorders with data loggers at non random locations (instrument type not specified)	Record will extend for weeks to months each year as required to estimate tidal datum and to calculate tidal prism (number and distribution of recorders not specified)
	Taxonomic composition and biomass of benthos and insects	Quantitative core sampling in each major habitat type	Annual collection of 1 random core along each of 10 transects (dimension and depth of core and length and distribution of transects not specified)
	Taxonomic composition and biomass of non-benthic invertebrates	Qualitative dip netting at random quadrats along transects in each major habitat	Annual collection with 3 net passes through in 1 random 0.5-sq m quadrat along each of 10 transects (length and distribution of transects not specified)
	Fish species composition and size distribution	Qualitative counts of number and size of individuals per species based on throw nets, variable-mesh gill nets, and bag nets at non-random stations	Annual in years 1-3, 7, and 10 (number and distribution of station not specified)
	Plant species composition, relative abundance, percent cover by species, height distribution	Quantitative counts along non-random transects through each major habitat type (count method i.e., visual estimate or point-intercept not specified)	Annual during peak growth period in years 1-5, 7, 10 at 8 transects (interval of counts and length and distribution of transects not specified)
	Bird species composition and habitat use patterns	Quantitative counts of individuals per species using non-random variable circular plots augmented by song playback surveys in each major habitat type	Seasonal surveys (1 each in spring and fall and 3 in winter) in early morning hours and various tidal stages at eight or more plots

Part B1: Example Wetland Projects

Project Name and (Reference #)	Parameter	Methods	
		Technique	Frequency
Ora Loma (11, 12, 13)	Channel geometry	Monumented non-random cross section surveys referenced to NGVD 29 (error of survey not reported)	Annual surveys of breech cross sections during winter or spring
	Sedimentation rate	Monumented non-random sedimentation pins	Annual measurements at 14 pins
	Tidal elevations, tidal regime	Recording pressure transducers (in situ model Troll SP4000) with data loggers at non-random locations tided to NGVD 29 (error of survey not reported)	Monthly and annual summaries of ongoing measurements at 12-min intervals for 4 recorders
	Plant species composition, relative abundance, percent cover by species, percent total cover	Quantitative visual counts in non-random plots along non-random transects in each major habitat type, plus maps of plant patches using geo-rectified aerial IR photos	Annual surveys in 25 1.0-sq m plots along each of 7 25-m long transects during peak growth period, plus annual aerial photos at scale 1:4,800
	Bird species composition, habitat use patterns	Qualitative counts of individuals in different feeding guilds for non-random plots in each major habitat	6 spring surveys (1 at high tide and 1 at low tide in April, May, June) in each of 9 plots of 10,000 to 15,000 sq m each

Part B2: Example Wetland Monitoring Programs

Project Name and (Reference #)	Parameter	Methods	
		Technique	Frequency
Suisun Marsh Monitoring Program (14)	Tide salinity, tide stage	Continuous in situ water level and conductivity recorders with data loggers (Enviro Lab DL-150 or DL-800 data loggers and Fisher-Porter or Stevens punch-paper tape recorders) at non random locations	Monthly and annual summaries from 1 station at each of 38 ponds based on 15-min intervals of measurement

Part B2: Example Wetland Monitoring Programs

Project Name and (Reference #)	Parameter	Methods	
		Technique	Frequency
Suisun Marsh Monitoring Program (cont'd) (14)	Soil salinity	Salinity of water pumped from soil tubes inserted below root zone measured at monumented, non-random locations (instruments not specified)	Monthly measurements at 3 replicate tubes in each pond (number of ponds varied and sample volume not specified)
	Pond water salinity and Ph	Field and laboratory measurements of water grabs at non-random stations (instruments not specified)	1 monthly 1-pnt sample from each of 14 ponds
	Pond hydroperiod	Continuous in situ water level recorders (Stevens Type F) plus staff gauges at non random locations	Monthly summaries and timing of key hydrologic events from 9 – 47 stations (number varies during 1982-1995) taken from physical charts
	Pond discharge salinity	Continuous in situ water level and conductivity recorders with data loggers (Enviro Lab DL-150 or DL-800 data loggers and Fisher-Porter or Stevens punch-paper tape recorders) at non-random locations	Monthly and annual summaries from 7 stations based on 15-min intervals of measurement
	Plant production	Quantitative counts of seeds of alkali bulrush and fat hen at monumented non-random plots in areas of obvious dense cover and high seed count near soil salinity stations	Annual counts (each autumn) for all seed heads within a single 1-sq m plot in each pond (number of ponds varies)

Part B2: Example Wetland Monitoring Programs

Project Name and (Reference #)	**Parameter**	**Methods**	
		Technique	**Frequency**
Suisun Marsh Monitoring Program (cont'd) (14)	Plant species distribution and abundance, and quantity of Salt marsh harvest mouse habitat	Quantitative map of plant assemblages based on ground-truthed natural color aerial photography and the NPS-USGS classification system in a GIS	Triennial maps of plant assemblages for entire program area (scale and timing of aerial photography not specified)
	Density and population size of Salt marsh harvest mouse	Quantitative estimates based on trap success and mark-recapture studies at non-random grids in selected habitat patches	Annual counts (first 2 years) and hence triennial counts for each of 100 live-traps for each of 3 trap nights in each of 7 habitat patches
	Neomysis, Acanthomysis	Quantitative counts based on bottom-to-surface oblique 10-min tows of plankton net (0.505-mm mesh; 30-cm diameter mouth, 1.48 m long), and zooplankton net (no. 10 mesh, 10-cm wide mouth, 73 cm long), plus microzooplankton sampled by pumping from throughout water column at non-random stations	Semi-monthly (1984-1995) and hence monthly collection of 2 zooplankton at each of 2 stations during various tie stages (boat speed not specified)
	Chlorophyll a	Quantitative measurements from water grabs at non-random stations used for Neomysis sampling (laboratory analysis not specified)	Semi-monthly (1984-1995) and hence monthly collection of 1 water grab from 1-m depth at each of 2 stations during various tide stages
	Fish diversity and abundance by species	Quantitative counts from 4-seam otter trawl (tapering mesh 35-mm to 6-mm, 1-m x 2.5-m opening, 5.3 m long) at monumented non-random stations	Monthly single tow (5-min at 4 km/hr in small sloughs, 10-min in large sloughs) at each of 21 stations during various tide stages

Part B2: Example Wetland Monitoring Programs

Project Name and (Reference #)	Parameter	Methods: Technique	Methods: Frequency
Suisun Marsh Monitoring Program (cont'd) (14)	Striped bass eggs and larvae	Quantitative counts from oblique tows of net (500-micron mesh, 3.18 m long) at monumented non-random stations	Daily single two for each of 8 days during spawning period at each of 36 stations during various tide stages
	Juvenile striped bass	Quantitative counts from oblique tows (net dimensions not specified)	Semi-monthly single 10-min tow at each of 32 stations at various tide stages during period of juvenile growth from 17.8 mm to 38.1 mm mean length
CWPPRA (15)	Project boundaries, habitat patch metrics and spatial distribution	Quantitative heads up digitizing of geo-rectified and ground-truthed color IR aerial photography with Cowardin-USFWS as default patch classification scheme in a GIS	Seasonal aerial photography (scale 1:12,000 or 1:24,000) of each project for one year pre-construction and at least 2 years post-construction
	Wind speed and wind direction	Continuous measurements using cup-and-propeller anemometers with data loggers set 6 m above level terrain	Hourly, daily, and monthly summaries in m/s for recorders set at each water level gage site
	Precipitation	Continuous measurements using tipping buckets with data loggers	Hourly and daily summaries in cm/hr for each wind speed recorder site
	Surface water levels	Simple staff gages or recording gages referenced to a common datum (1-cm vertical survey precision)	Occasional staff gage readings and daily and monthly summaries of continuous recordings (number and distribution of stations not specified)

Part B2: Example Wetland Monitoring Programs

Project Name and (Reference #)	Parameter	Methods	
		Technique	Frequency
CWPPRA (cont'd) (15)	Groundwater levels	Simpler PVC piezometers or recording gages over wells references to a common datum (1-cm vertical survey precision)	Occasional piezometer readings and daily and monthly summaries of continuous recordings (number and distribution of stations not specified)
	Salinity and temperature	Refractometers and probes for spot measurements and recording and electrical conductivity or inductivity meters with internal temperature corrections and with data loggers	Occasional spot measurements and daily and monthly summaries from continuous recorders in ppt (number and distribution of stations not specified)
	Discharge	Continuous measurements using mechanical, electromagnetic or acoustical meters at 0.6 of depth (adjusting to changing stage) in center of channel at monumented cross-sections	Hourly, daily, and monthly summaries in m^3/sec (number and distribution of stations not specified)
	Suspended sediment	Depth- and velocity-integrated measurements using pumps, USGS D84 style hand-held samplers, or optical meters	One series of depth- and velocity-integrated measurements in mg/L for one spring and one neap tide at least 6 times per year (number and distribution of stations not specified)

Part B2: Example Wetland Monitoring Programs

Project Name and (Reference #)	Parameter	Methods	
		Technique	Frequency
CWPPRA (cont'd) (15)	Bathymetry	Cross sectional surveys of channel form extending from marsh plain across channel and including breaks in slope and thalweg referenced to common datum (1-cm vertical precision)	One cross section at each discharge station (number and distribution of stations not specified) measured annually; other cross sections as needed to describe channel form
	Bulk density, total organic matter, g rain size, percent water	Quantitative non-random coring with piston corers to prevent compaction; standard lab methods of analysis	Annual cores of 50 cm^3 each to depth of 11 cm (number and distribution of stations not specified)
	Soil salinity	Measurements using conductivity meters for interstitial water centrifuged from non-random soil cores	Monthly measurements in ppt from cores in root zone (number and distribution of stations not specified)
	Groundwater salinity,	Vertical profiles at non random stations using pumps or pipettes (sampling tubes) to extract water from 1.3–cm perforated PVC pipes capped at bottom and inserted to different depths	Monthly measurements in ppt from surface to below root zone in geometric series across marsh plain from channel bank (number and distribution of stations not specified).
	Soil sulfide	Standard lab analysis of water extracted from soil at non-random plots using syringe fitted to stainless steel tube	Monthly measurements in ppm for 15 cm below ground surface (number and distribution of stations not specified)

Part B2: Example Wetland Monitoring Programs

Project Name and (Reference #)	Parameter	Methods	
		Technique	Frequency
CWPPRA (cont'd) (15)	Soil redox	eH electrode inserted intro soil at non random plots	Monthly measurements in mV at 15 cm depth in soil (number and distribution of stations not specified)
	Average marsh elevation,	Average value for network of non-random point measurements of ground height relative to survey instrument (1-cm vertical survey precision)	Annual occupation of 20 points, each one separated by 5 to 10 m
	Vertical accretion rate	Measurements of depth of sediment above feldspar marker horizon using frozen sediment cores at non-random stations referenced to common datum (1-cm vertical survey precision)	Annual measurements in mm/year within 0.25-m^2 feldspar layer at least 5-mm thick
	Subsidence rate	Surveys of average marsh surface relative to historical tidal benchmarks not subject to subsidence (1-cm vertical survey precision)	Annual occupation of network of 20 points, each one separated by 5 to 10 m (number and distribution of networks depends on availability of historical benchmarks)
	Vertical erosion	Sedimentation Erosion Table (SET), or measures of depth of C^{137} horizon in non-compacted sediment cores taken with piston corer at non-random stations	Annual measurements at each corner of each plot (number and distribution of plots not specified)
	Small-scale (local) horizontal erosion	Repeated non-random surveys of marker stakes or measures of distance to shoreline from monumented points (horizontal survey precision not specified)	Annual measurements in m/year (number and distribution of measurements not specified)

Part B2: Example Wetland Monitoring Programs

Project Name and (Reference #)	Parameter	Methods	
		Technique	**Frequency**
CWPPRA (cont'd) (15)	Plant species composition, relative abundance, biomass	Quantitative species-area curves, point frame counts, and clippings for random single-and multiple-canopy plots	Annual summer surveys (size, number, and distribution of plots not specified)
	Herbivory rate	Quantitative comparison of plant biomass inside and outside exclosures a randomly chosen fixed plots	Annual measurements of biomass (dimensions, number, and distribution of exclosures not specified)
	Fish species composition, species richness, density, size distribution, biomass	Quantitative samples of adult and juvenile fishes using throw traps, drop boxes, trawls and seines as appropriate at non-random stations	Semi-annual or annual measurements in catch-per-standard-unit-of effort (CPUE) (trap dimension and the number and distribution of stations not specified)
	Trace metals, PCBs, pesticides, PAHs, TOC, and nutrients in water and sediment	Standard laboratory analyses of sediments taken with gravity coring devices or piston corers and of surface water grabbed in buckets or by pumping at random plots within strata including expected sites of contamination as one stratum	Annual measurements (number and description of strata ad number and dimensions of plots within strata not specified)

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3. 1997-1998 Annual Monitoring Report Sonoma Baylands Wetland Demonstration Project. US COE 1999.

4. Sonoma Baylands Wetland Demonstration Project Monitoring Plan. USCOE and California Coastal Conservancy, 1996

5. Biological Monitoring Plan for Cullinan Ranch and Tolay Creek Units. USGS, USFWS, Duck Unlimited, 1999

6. Ecological Monitoring of Tolay Creek and Cullinan Ranch Tidal Wetland Restoration Projects in the North San Francisco Bay. USGS, USFWS, Duck Unlimited, 2001

7. Performance based Hydraulic Monitoring and Maintenance – Napa River Flood Protection Project and O&M Manual. USCOE and Napa County Flood Control and Water Conservation District, 2000

8. Napa River Flood Protection Project Mitigation and Monitoring Plan. USCOE and Jones & Stokes, 2000

9. Petaluma Demonstration Wetlands project Compensation, Monitoring and Management Plan. City of Petaluma, 1998.

10. Mitigation Monitoring Plan for the Sonoma Creek Bridge Seismic Retrofit and Barrier Placement Project Petaluma Marsh Expansion Project. Caltrans, 1999.

11. Monitoring Plan for the Ora Loma Marsh. Levine-Fricke, 1996.

12. Ora Loma Monitoring Report: 1997-1999. Lenington Ecological Services, 2000.

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14. Suisun Marsh Monitoring Program Reference Guide version 2. DWR, 2000

15. CWPPRA (Louisiana Coastal Planning, Protection, and Restoration Act) Monitoring Plan. Coastal Restoration Division, Louisiana Department of Natural Resources, 2000.

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Bay Point Regional Shoreline Restoration Plan. East Bay Regional Park District, 1999.

Canal Ranch Habitat Restoration Phase III Demonstration Project. CDFG, 2000

Feasibility Analysis for the San Joaquin River – Bear Creek Floodplain Restoration Project San Luis National Wildlife Refuge, Merced County. USFWS, 1997.

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Mill Creek Riparian Restoration Project Scope of Services. Mill Creek Conservancy, 1998.

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Restoring Ecosystem Integrity in the Northwest Delta. Solano County Farmlands and Open Space Foundation, 1998.

Robinson/Gallo Restoration Project Monitoring Plan. CDFG and DWR, 1999.

Sacramento River – Active Restoration of Riparian Forest. CDFG, USFWS, The Nature Conservancy, 1998.

Sacramento River Meander Belt Implementation Project. The Nature Conservancy, 1998.

Scope of Services for Demonstration Project for the Protection and Enhancement of Delta In-Channel Islands. Association of Bay Area Governments, 1998.

The Butte Creek Riparian Protection ands Restoration Plan. California State University at Chico and Butte Creek Watershed Conservancy, 1998.

Work plan for the Evaluation and Demonstration of Techniques for Reversing the Effects of Subsidence in the Sacramento-San Joaquin Delta. DWR. USGS, Northwest Hydraulic Consultants, Natural Heritage Institute, Philip Williams and Associates, Steve Deverel, 1998.

Program Documents

New York State Marsh Restoration and Monitoring Guidelines. 2000. New York State Department of State, Division of Coastal Resources, Albany, NY. *This program contains relatively few indicators at this time, although it contains a wealth of conceptual modeling to support more indicators.*

The Marsh Monitoring Program 1995-1999: Monitoring Great Lakes Wetlands and their Amphibian and Bird Inhabitants. 2000. Environment Canada..

APPENDIX D
Table of Expected Relationships Between Spatial-Temporal Scales and State and Pressure Indicators

Spatial Scale, Sampling Strata, Indicator Category, Example State Indicators	**Ecosystem Compartment of State Indicator**	**Sampling Frequency or Periodicity of Data Summaries as Proxies for Temporal Scale**	**Major Ecosystem Compartments for which State Indicators Are Also Pressure Indicators** PPT = Physical Processes; C = Contaminants; P = Plants; I = Invertebrates; F = Fish; ARM = Amphibians, Reptiles or Small Mammals; B= Birds						
Within and Between Sites			**PPT**	**C**	**P**	**I**	**F**	**ARM**	**B**
Small Channels and Large Channels (two separate strata)									
Hydrologic and Edaphic Indicators									
Tidal Elevation	PPT	Seasonal	X	X	X	X	X	X	X
Tidal Hydroperiod and Prism	PPT	Seasonal	X	X	X	X	X	X	X
Total Suspended Sediment	PPT	Seasonal	X	X	X	X	X		X
Sedimentation Rate	PPT	Seasonal	X	X	X	X			
Water Salinity	PPT, C, F	Seasonal	X	X	X	X	X	X	X
Benthic Sediment Grain Size	PPT, C	Seasonal	X	X		X	X		
TOC	C	Seasonal	X	X		X	X		
Dissolved Oxygen	PPT	Seasonal	X	X		X	X	X	
Water Temperature	PPT, C	Seasonal	X	X		X	X	X	
Water pH	PPT, C	Seasonal	X	X	X	X	X	X	X
Water Chlorophyll Content	PPT	Seasonal		X	X	X	X		
Water Ammonium/Nitrate	PPT	Seasonal		X	X	X	X		
Channel Geometry	PPT	Annual	X	X	X	X	X	X	X
Sediment Trace Elements	C	Annual		X	X	X	X	X	X
Sediment, Water, Tissue Hg and MeHg	C	Annual		X	X	X	X	X	X
Sediment, Water, Tissue PCB’s and Pesticide Residues	C	Annual		X	X	X	X	X	X
Water Total Organic Content	C	Annual	X	X	X	X	X		
Biological Indicators									
Plant Community Structure	P	Annual	X	X	X	X	X	X	X
Benthic Invertebrate Community Structure	I	Seasonal				X	X	X	X
Fish Community Structure	F	Seasonal				X	X	X	X
Amphibian and Reptile Community Structures	F, ARM	Seasonal			X	X	X	X	X
Small Mammal Community Structure	ARM	Seasonal				X	X	X	X
Passerine and Rail Community Structures	B	Seasonal				X	X	X	X
Shorebird and Wading Bird Community Structures	B	Seasonal			X	X	X	X	X

Table of Expected Relationships Between Spatial-Temporal Scales and State and Pressure Indicators (cont'd)

Spatial Scale, Sampling Strata, Indicator Category, Example State Indicators	**Ecosystem Compartment of State Indicator**	**Sampling Frequency or Periodicity of Data Summaries as Proxies for Temporal Scale**	**Major Ecosystem Compartments for which State Indicators Are Also Pressure Indicators** PPT = Physical Processes; C = Contaminants; P = Plants; I = Invertebrates; F = Fish; ARM = Amphibians, Reptiles or Small Mammals; B= Birds						
Within and Between Sites (cont'd)			**PPT**	**C**	**P**	**I**	**F**	**ARM**	**B**
Marsh Plain, Backshore, Foreshore (three separate strata)									
Hydrologic and Edaphic Indicators									
Tidal Elevation	PPT	Seasonal	X	X	X	X	X	X	X
Tidal Hydroperiod	PPT	Seasonal	X	X	X	X	X	X	X
Soil pH or Redox Potential	PPT	Seasonal	X	X	X	X	X		X
Sedimentation Rate	PPT	Seasonal	X	X	X	X			
Root Zone Salinity	PPT, C, F	Seasonal	X	X	X	X	X	X	X
Root Zone Bulk Density	PPT	Seasonal	X	X		X	X	X	
Root Zone Dominant Grain Size	PPT, C	Seasonal	X	X		X	X	X	
Root Zone Soil Water Content	PPT, C	Seasonal	X	X	X	X	X	X	X
Plant Tissue Salinity	P, PPT	Seasonal		X	X	X	X		
Biological Indicators									
Plant Community Structure	P	Annual	X	X	X	X	X	X	X
Invertebrate Community Structure	I	Seasonal				X	X	X	X
Amphibians and Reptiles Community Structures	F, ARM	Seasonal			X	X	X	X	X
Small Mammal Community Structure	ARM	Seasonal				X	X	X	X
Passerine and Rail Community Structures	B	Seasonal				X	X	X	X
Shorebird and Wading Bird Community Structures	B	Seasonal			X	X	X	X	X
Whole Sites									
Biological Indicators									
Plant Species Richness	P	Annual	X		X	X	X	X	X
Invertebrate Species Richness	I	Annual			X	X	X	X	X
Vertebrate Species Richness	F, B, ARM	Annual			X	X	X	X	X
Ratio of Native to Non-native Species	P F, B, ARM	Annual	X		X	X	X	X	X
Meso-Predators	F, B, ARM	Annual				X	X	X	X

Table of Expected Relationships Between Spatial-Temporal Scales and State and Pressure Indicators (cont'd)

Spatial Scale, Sampling Strata, Indicator Category, Example State Indicators	**Ecosystem Compartment of State Indicator**	**Sampling Frequency or Periodicity of Data Summaries as Proxies for Temporal Scale**	**Major Ecosystem Compartments for which State Indicators Are Also Pressure Indicators** PPT = Physical Processes; C = Contaminants; P = Plants; I = Invertebrates; F = Fish; ARM = Amphibians, Reptiles or Small Mammals; B= Birds						
Within and Between Sites (cont'd)			**PPT**	**C**	**P**	**I**	**F**	**ARM**	**B**
Whole Sites (cont'd)									
Hydrologic, Edaphic, Geographic Indicators									
Mean Tidal Range	PPT	Annual	X	X	X	X	X	X	X
Average Tidal Prism	PPT	Annual	X	X	X	X	X	X	X
Mean and Maximum Water Salinity Range	PPT	Annual	X	X	X	X	X	X	X
Mean and Maximum Root Zone Salinity Range	PPT	Annual		X	X			X	
Maximum Contaminant Levels	C	Annual			X	X	X	X	X
Adjacent Land Uses and Infra-Structure	PPT, P	Annual	X	X	X	X	X	X	X
Habitat Patch Complexity	PPT, P	Annual			X	X	X	X	X
Within and Between Landscapes and Subregions									
Whole Landscapes									
Landscape Ecology Indicators									
Adjacent Land Uses and Infra-Structure	PPT, P	Annual	X	X	X	X	X	X	X
Habitat or Plant Community Mosaics	P, F, B, ARM	Annual	X		X	X	X	X	X
Total Areas of Habitats or Plant Communities	P, F, B, ARM	Annual	X	X	X	X	X	X	X
Habitat or Plant Community Patch Size Frequencies	P, F, B, ARM	Annual	X	X	X	X	X	X	X
Habitat Patch Shape Frequency	P, F, B, ARM	Annual	X	X	X	X	X	X	X
Habitat Patch Isolation	P, F, B, ARM	Annual	X	X	X	X	X	X	X
Habitat or Plant Community Fragmentation	P, F, B, ARM	Annual	X	X	X	X	X	X	X
Total Length of Backshore and Foreshore	PPT, P	Annual	X	X	X	X	X	X	X