SOUTH BAY SALT POND RESTORATION PROJECT
DRAFT SCIENCE PLAN
October 1, 2004

I. Introduction

The overarching goal of the South Bay Salt Pond Restoration Project (Project) is the "restoration and enhancement of wetlands in the South San Francisco Bay while providing for flood management and wildlife-oriented public access and recreation". Many planning decisions will be made to achieve this goal and the specific Project Objectives. A vigorous science program will inform project managers and stakeholders what end results are achievable and will improve the likelihood of achieving the Project Objectives.

An effective science program will also generate critical information during the entire life of the Project. The planning period for the Project is focused on developing a Phase 1 project to be implemented by 2008. This will be the first of many phases in this long-term restoration, all of which will require a strong scientific basis. That basis must be built on what we currently know and on what we can learn from the Project as it proceeds. Scientific knowledge must be developed through an iterative process in which critical information is generated and then applied to the Project through adaptive management. The South Bay Salt Pond Restoration Project Science Plan (Science Plan) outlines a science program that will contribute to the planning and implementation of the Project. Specifically, the Science Plan provides the *content basis* and *process* for the collection, synthesis and dissemination of the best available science for the Project and to support the adaptive management necessary to achieve Project Objectives.

The three pillars of this Plan are the <u>Broad Science Questions and Key Science Issues</u>, which are central to achieving Project Objectives; <u>Science Syntheses</u> that provide the state of the science on the Project Objectives; and the <u>Science Structure</u> that implements an on-going process of evaluating key questions, collecting and synthesizing information, disseminating the data to decision-makers, and evaluating restoration progress.

Specifically, the sections of the Science Plan are:

<u>**Content Elements**</u>

II. **Providing a scientific analysis of the Project Objectives;**
III. **Identifying Broad Science Questions and Key Science Issues;**
IV. **Preparing Science Syntheses;**
V. **Identifying Preferred Performance Standards and Measures for Restoration Progress;**
VI. **Assessing Our Predictive Abilities;**
VII. **Identifying Key Uncertainties** (short- and long-term, including tools needed to reduce uncertainty);
VIII. **Making Science-based Recommendations for Planning, Design and Implementation.**

Process Elements

IX. **Instituting a Science Structure** (a structure and process for generating information to address the key questions and uncertainties, for implementing the Adaptive Management Plan and for integrating the data into Project decision-making);

X. **Integrating Science into the Project** (including integration with management decision-making, Science Team and Consultant Team integration, a timeline for Science Team product development linked to project milestones, and a budget for science support to the Restoration Project).

Each element of the Plan brings science into critical decision-making steps and/or provides the foundation for the generation of new scientific information in the short- and long-term.

The Science Plan will also provide the scientific foundation for developing and implementing the Adaptive Management Plan. The Adaptive Management Plan, which will be a future companion document to this Science Plan, will describe the methodology for collecting new scientific information via applied studies (monitoring, targeted experiments, and research) during planning and implementation, and then acting on that information. Information gained through this process can be used to:

- modify past restoration actions;
- revise future restoration actions, monitoring and applied studies; and/or
- revise the assumptions and knowledge base for the Restoration Plan.

Figure 1 illustrates the relationship between the Science Structure and the overall South Bay Salt Pond Restoration process.

II. Providing a Scientific Analysis of the Project Objectives

The mission of the South Bay Salt Pond Restoration Project during the planning stage is "to prepare a scientifically sound and publicly supported restoration and public access plan that can begin to be implemented in five years". The organizational structure of the Restoration Project (Figure 2) designed to achieve this goal includes the Executive Leadership Group and Project Management Team (PMT), who are the Project decision-makers. An extensive Stakeholder process, including regulatory agencies, provides input to the PMT. Science input and development is accomplished by the Science Structure (Figure 3), which includes a local Science Team and an advisory National Science Panel.

The Project Objectives (see Table 1) were developed collaboratively by the Stakeholders and the PMT. These Objectives are general and some may be conflicting. To better guide the restoration toward feasible and achievable goals, the Project Objectives require a scientific basis, grounded in the literature and linked to Conceptual Models. The scientific analysis of the Project Objectives will be a description of the Objectives based on the literature that: 1) identifies uncertainties and conflicts in the Project Objectives and likely restoration outcomes, and 2) provides feasible performance standards and measures for assessing restoration progress. The Project Objectives analysis will be based on the Science Syntheses and Conceptual Models developed for the Science Plan.

The schedule for completing the Science Plan is as follows:

Preliminary Summaries of Syntheses Prepared	Sept 15, 2004
First Draft Science Plan Completed	Sept 28
Draft Science Syntheses Completed and sent to Peer Reviewers	Oct 15
Focused Conceptual Model First Drafts Completed; Sent to entire Science Team and PMT for Review	Nov 1
Science Team Review of Conceptual Models Completed	Dec 1
Peer Review of Science Syntheses Completed	Dec 1
Science Synthesis and Summary Revisions Complete	Jan 15, 2005
Final Draft Science Plan Complete; Sent to Science Team for Review	Feb 1
Comments from Science Team Complete	Feb 15
Final Science Plan Complete	Feb 28

These steps are currently in progress and this Draft Science Plan includes drafts of the content that will be used to ground the Project Objectives in science. Since the elements are not complete, scientific analysis of the Project Objectives is not included in this draft, but will be part of the final Science Plan.

Table 1. Project Objectives

Objective 1. Create, restore, or enhance habitats of sufficient size, function, and appropriate structure to:

A. **Promote restoration of native special-status plants and animals that depend on South San Francisco Bay habitat for all or part of their life cycles.**
B. **Maintain current migratory bird species that utilize existing salt ponds and associated structures such as levees.**
C. **Support increased abundance and diversity of native species in various South San Francisco Bay aquatic and terrestrial ecosystem components, including plants, invertebrates, fish, mammals, birds, reptiles and amphibians.**

Objective 2. Maintain or improve existing levels of flood protection in the South Bay area.

Objective 3. Provide public access opportunities compatible with wildlife and habitat goals.

Objective 4. Protect or improve existing levels of water and sediment quality in the South Bay and take into account ecological risks caused by restoration.

Objective 5. Implement design and management measures to maintain or improve current levels of vector management, control predation on special status species and manage the spread of non-native invasive species.

Objective 6. Protect the services provided by existing infrastructure (e.g. power lines).

III. Identifying Broad Science Questions and Key Science Issues

The process of founding the Project Objectives in science begins with identifying the science issues that will drive the restoration. The Science Team identified four Broad Science Questions that “will drive the science for years ahead” (NSP 2004). These Broad Questions are expected to remain relatively unchanged through the life of the Restoration Project. The Broad Science Questions driving the science are:

A: How will the physical structure of the South Bay ecosystem and the larger Bay ecosystem, including all habitat components, evolve during and after restoration actions?
A central question is how the project area is going to evolve physically over the next several decades; the overall sediment budget for South Bay is a primary factor in this evolution. Large uncertainties in our understanding of this budget make the evaluation and prediction of how these habitats will evolve highly uncertain. Hydrology, including wave action effects and sea-level rise, will also influence physical structure. Local variations, both in time and in space, in the rates of accretion, erosion and vegetative colonization compound uncertainties, as do long-term uncertainties due to climate change and variability, including changes in sea level and the hydrology of the San Francisco Bay watershed. While restoration activities are expected to increase tidal marsh habitat, the sediment budget and hydrology will be primary determinants in how much marsh can be restored. Restoration activities are expected to produce positive effects with respect to South Bay ecosystem function, but there could also be unwanted results such as the loss of significant areas of mudflat. Positive and negative changes must be evaluated.

Large changes in physical processes and structures of the South Bay may lead to fundamental shifts in the ecosystem for other parts of San Francisco Bay, particularly the Central Bay. Perhaps more importantly, the mobilization of contaminants, particularly mercury, could have impacts in Central Bay and even the coastal ocean. Further, the fact that the Project will lead to (uncertain) changes in the sediment dynamics of South Bay could lead to changes in the exchange of sediment between South Bay and Central Bay, potentially altering the conditions in the Central Bay. More directly, the restoration of habitat in South San Francisco Bay will have broader implications due to movement of individuals, such as birds moving along the Pacific flyway. In order to evaluate the effects and implications of restoration activity, these broader considerations must be included.

B: What will be the physical and ecological quality of the habitat components of the South Bay ecosystem as a result of restoration activity?
Restoration actions will be designed to increase habitat quality, as well as quantity. But, the links between restoration actions and habitat quality must be clear. The quality of habitat resulting from restoration activities will be a function of the local water and sediment quality, including the salinity, oxygen concentrations, and the amounts, types and forms of contaminants present. An important consideration during the restoration activities will be how the actions taken may affect these conditions both within and outside the project area. With regards to contaminants, the amount of mercury present in the sediments in the project area and the mobilization of the mercury through methylation both provide important sources of uncertainty in our ability to forecast the impacts of restoration actions. Further, there is uncertainty about the presence of, and ecosystem impacts of, other contaminants on the project sites. Finally, it is expected that the project will affect the local salinity and dissolved oxygen conditions (which has been established through the Initial Stewardship Plan monitoring activities) and perhaps even the tidal dynamics along much of South Bay – which may have important implications for the local habitats as well as those along the rest of South Bay. Ecological factors will also influence habitat quality, especially the presence of non-native invasive species such as *Spartina*

alterniflora, which may reduce habitat quality for a number of species. While restoration activities are expected to be overwhelmingly positive for many native species, they may lead directly to the spread of invasive organisms.

C: How will the South Bay ecological communities, especially target species and communities, respond to restoration activities, particularly in view of the urban setting?
For this Project, the population responses of target species are essential measures of restoration progress. While these responses will depend on landscape structures and processes (Question A) and habitat quality (Question B), species' responses are often unpredictable and must be assessed directly. For example, there is a great deal of uncertainty about the habitat value of the various pond types and pond characteristics that are being considered. Similarly, the habitat needs of many rare and endangered species are not well understood. These issues are particularly pronounced when one considers that the restoration activity being undertaken sits in the middle of a densely-populated urban environment, and that human interaction with the habitats is part of the restoration plan. Beyond the planned human interaction with the habitat, the indirect effects of the population are likely to be felt through invasive species, including those that have already been introduced as well as those that may be introduced at some point during the project lifetime. In view of all of these issues, even if the amount, type and quality of habitat were known, the use of the habitats, particularly by target species, is uncertain. Answers to this broad question require assessment of species responses (especially behavior and population measures) to different pond management regimes, habitat quantities and qualities, native and non-native invasive species, and public assess/recreation.

D: What will the public expect from the restoration project, especially with respect to flood control, vector control, infrastructure, and public access/recreation?
This Project is located in a highly urbanized area. Over 7 million people live in the counties surrounding the Bay and their expectations will significantly influence restoration activities and outcomes. For example, pond odor, mosquitoes, and the safety of eating Bay fish are well-known public concerns already being addressed by the Project. Expectations for public access and flood protection are two Objectives of the project because they are crucial to public support and stewardship. Public attitudes and satisfaction with the restoration will have direct implications for funding, public support, and the future of restoration in the Bay. The Project must track trends and changes in public expectations that may affect restoration outcomes and include mechanisms for engaging the public and addressing significant issues. This question brings social science issues into the realm of the "science" issues central to the Project. The fact that this question is relevant to all the Project Objectives makes its importance clear.

Within these four Broad Questions, Nine Key Science Issues have been identified that are critical to the planning, implementation and adaptive management of the Project. These Key Issues focus on ecological and restoration issues central to attaining Project Objectives.

<u>Key Science Issues</u>

1. **Maintaining and improving functioning of the South Bay ecosystem.**
2. **Incorporating knowledge of the sediment budget and sediment dynamics in restoration design.**

3. **Restoring tidal salt marsh and associated habitats over the next 50 years at pond and pond-complex levels.**
4. **Assisting the recovery of special status and other indicator species using the restoration of ecosystem function and tidal salt marsh and associated habitats.**
5. **Managing salt ponds to protect migratory bird diversity and abundance.**
6. **Predicting impacts of hydrological modifications from salt pond management and ecosystem restoration actions.**
7. **Predicting pollutant effects on the biological functioning of the South Bay.**
8. **Limiting the impact of invasive species and other nuisance species.**
9. **Minimizing the negative ecosystem effects of human-related activities and infrastructure.**

These Issues are focused, researchable topics selected based on their relevance to the Project Objectives and to the Broad Science Questions. The Key Issues are likely to evolve and change as our knowledge grows while the Broad Science Questions will likely remain unchanged. The nine Key Issues serve as the basis for the development of the Science Syntheses. The relevant Project Objectives and Key Issues are mapped to the four Broad Science Questions, below.

A: How will the physical structure of the South Bay ecosystem and the larger Bay ecosystem, including all habitat components, evolve during and after restoration actions?
Relevant Project Objectives: 1, 2
Relevant Key Issues: 1, 2, 3, 6

B: What will be the physical and ecological quality of the habitat components of the South Bay ecosystem as a result of restoration activity?
Relevant Project Objectives: 1, 3, 4, 5
Relevant Key Issues: 6, 7, 8

C: How will the South Bay ecological communities, especially target species and communities, respond to restoration activities, particularly in view of the urban setting?
Relevant Project Objectives: 1, 3, 5
Relevant Key Issues: 1, 3, 4, 5, 7, 8, 9

D: What will the public expect from the restoration project, especially with respect to flood control, vector control, infrastructure, and public access/recreation?
Relevant Project Objectives: 1, 2, 3, 4, 5, 6
Relevant Key Issues: 4, 5, 6, 7, 8, 9

IV. Preparing Science Syntheses

Introduction. As the next step in understanding the feasibility of the Project Objectives, the Science Team is writing Science Syntheses (literature reviews focused on the Project Objectives) for each Key Issue that summarize our understanding of the functioning of the South Bay ecosystem and restoration outcomes. Each synthesis is a review of what we know, what we don't know, and what we need to know to achieve the Project Objectives. These syntheses are designed to provide a scientific basis for developing:

- an analysis of the Project Objectives,
- key questions/uncertainties to be addressed through a competitive proposal process,
- performance standards and measures for Alternatives development and the Adaptive Management Plan, and
- the Adaptive Management Plan for short and long-term data collection and project improvement.
- recommendations to be used in Alternatives development and Phase 1 design.
- Conceptual Models

Regular updates of these Syntheses will provide the most current scientific information for Project Milestones during planning, Phase 1 implementation. Table 2 shows Project Milestones through 2008 and the science products, most from the Science Syntheses, that will contribute to each step. As the table shows, the science products will evolve and be revised throughout the planning process. Here are brief descriptions for how the science products will contribute to each 2004-2005 milestone:

Initial Project Options: At this milestone, the Consultant Team with PMT, Stakeholder and Science Team input will produce a range of potential restoration scenarios that can be refined into alternatives. The Science Syntheses and Key Issues will be used to show where outcomes are most and least certain and where constraints exist for each option. The Recommendations will give suggestions for specific actions that should be included in some or all options to achieve Project Objectives and minimize constraints or conflicts. The Key Questions will to used to determine short-term questions, specific to alternatives development, that can be answered in the planning period.

Existing Conditions: The Science Syntheses may provide information on existing Project area conditions and show deficiencies in our understanding of reference conditions. Key Questions can be used to point out questions on existing conditions that should be acknowledged or, if possible, addressed in the planning phase.

Landscape Level Modeling: The Consultant Team will conduct computer modeling to predict changes in landscape features over time under different restoration options. The modelers on the Science Team have commented a number of times on the consultants' proposed modeling strategies. The Analysis of Modeling Strategies memo is a formal report on this topic. Information from the Science Syntheses on predictive tools will be provided to the Consultant Team to assist in choosing and designing models.

Initial and Final Alternatives: The Consultant Team will turn Project Options into Alternatives for the EIR/EIS. These very critical products require significant scientific input. The consultants must use conceptual models and science syntheses to justify restoration actions and describe the level of certainty. The Performance Standards/Measures and science analysis of the Project Objectives will be developed by the Consultant Team into quantitative metrics for evaluating the ability of each alternative to meet the Project Objectives. The Science Team will identify Key Issues and Questions that should be answered through applied studies in the Phase 1 implementation.

Initial Competitive Proposal Process: The Science Team will identify the most critical short- and long-term questions based on the Science Syntheses to be included in a 2005 call for proposals. This call will result in the first round of applied studies for the Project. The questions chosen must begin implementing data collection for adaptive management and must address pressing management decisions.

While huge literature reviews could be written about each of the Key Issues, the Syntheses are more narrowly focused *specifically on the Project Objectives*. Each Science Synthesis addresses these points:

- What is the importance of the Issue as it relates to the Project Objectives?
- What do we know about this Issue as it relates to the Project?
- What is the level of certainty of our knowledge?
- What predictive tools exist for gaining an understanding of this Issue and what tools are needed to reduce uncertainty to an acceptable level?
- What are potential restoration targets and performance measures, linked to the Objectives, for evaluating the progress of the restoration project?
- What management measures might be used to reduce negative impacts or achieve positive ones?
- What key questions essential to the success of the restoration need to be addressed through targeted experiments, monitoring, or research?

The Science Syntheses are the heart of the Science Plan, and at this point, are still in production. When completed, the Syntheses will be peer reviewed and the information in them will be used to complete this Plan. See the schedule on page 2 of the Science Plan for their completion date.

Table 2. Science Input Into Project Milestones

Science Team Product	Date	Project Milestone	Date
Key Issues & Questions	10/04	Initial Project Options	11/04
Science Syntheses (1st draft)	10/04		
Recommendations for Planning, Design and Implementation (1st draft)	10/04		
Science Syntheses (2nd Draft)	1/05	Existing Conditions (draft)	2/05
Key Questions (2nd Draft)	1/05		
Report: Analysis of Modeling Strategies	10/04	Landscape Level Modeling	2/05
Tools Available/Needed (1st Draft)	10/04		
Conceptual Models (draft)	1/05	Initial Alternatives (draft)	1/05
Key Issues and Questions (draft)	12/04		
Science Syntheses (draft)	10/04		
Performance Criteria (draft)	10/04		
Science Analysis of Project Objectives (draft)	12/04		
Science Syntheses	3/05	Initial Competitive Proposal Process	3/05
Key Questions--short- and long-term (revised)	3/05		
Adaptive Management Plan (draft)	4/05		
Conceptual Models (revised)	3/05	Final Alternatives	7/05
Science Syntheses (as in Science Plan)	3/05		
Performance Standards and Measures (final)	3/05		
Analysis of Model Strategies	10/04		
Science Analysis of Project Objectives (final)	3/05		
Adaptive Management Plan (draft)	4/05		
Report: Scientific Basis for Alternatives Selection	4/05		

Science Team Product	Date	Project Milestone	Date
Report: Evaluation of Preliminary Impact Summary	11/05	Final Impact Analysis Summary	6/06 (approx.)
Recommendations for Planning, Design, and Implementation (revised)	9/05	Preliminary Design (Phase 1)	2/06 (approx.)
Science Syntheses (revised)	1/06	Final Design (Phase 1 Plans and Specs)	3/07-12/07
Tools Available (revised)	3/06		
Recommendations for Planning, Design and Implementation (revised)	3/06		
Analysis of Model Strategies (revised)	3/06		
Conceptual Models (revised)	3/05	ROD	4/07
Science Analysis of Project Objectives (final)	3/05		
Science Syntheses (revised)	12/06		
Performance Standards and Measures (final)	3/05		
Key Questions/Uncertainties (revised)	1/07		
Applied Studies Results	1/07		
Adaptive Management Plan (final)	7/05		
Science Syntheses (revised)	2007	Phase 1 Implementation	2008
Key Questions/Uncertainties (revised)	2007		
Adaptive Management Plan (final)	2007		
Applied Studies Results	2007		

Importance of Each Key Issue to the Project Objectives. The Syntheses are being prepared by subject matter experts, including members of the Science Team and others (see Appendix 1). For this draft Science Plan, authors of each Synthesis *condensed* their findings into relatively short summaries, which are found in Appendix 2. In this section, the reasons why the Issues are relevant to the Project Objectives are stated. All materials in this section and the next three sections were taken verbatim from the first draft *summaries* of the Science Synthesis in

Appendix 2. *At the time of this Draft Science Plan, most authors were still in the process of researching and writing their complete Science Syntheses*. Some syntheses were not complete enough even for a summary. The summaries included here are very much first drafts and are incomplete. The information provided is designed to show the direction of the Science Plan development and the type of information that will be included as the basis for science planning. With that disclaimer, the importance of each Issue to the Project Objectives is briefly stated below.

<u>Objective 1. Create, restore, or enhance habitats of sufficient size, function, and appropriate structure to:</u>

<u>1A. Promote restoration of native special-status plants and animals that depend on South San Francisco Bay habitat for all or part of their life cycles, and</u>

<u>1C. Support increased abundance and diversity of native species in various South San Francisco Bay aquatic and terrestrial ecosystem components, including plants, invertebrates, fish, mammals, birds, reptiles and amphibians.</u>
<u>(based on Key Issues 1, 2, 3, 4, 6—Only Issues 1, 2, 3 is included so far)</u>

Landscape and Habitat Change (Issues 1 & 3). Meeting the Project objectives according to the design principles will require scientific understanding of the relative influence of natural processes and land use on the quantity and quality of all the major types of habitat that span the tidal gradient from adjacent uplands and fluvial systems through the intertidal and diked baylands to the subtidal areas of South San Francisco Bay. This broad view is required because in essence the Project occupies the transition zone between terrestrial and aquatic-estuarine systems and thus some portion of the ecological services of the Project depend on adjacent processes, and some of the adjacent processes will be affected by the Project. Furthermore, the recommended approach and emerging design principles for the Project emphasize deference to natural processes of the lands and waters of the South Bay Ecosystem to meet the objectives with minimal infrastructure and management.

<u>Sediment Management</u> (Issue 2). Project objective 1 is to create, restore, or enhance habitats of sufficient size, function, and appropriate structure to promote restoration and support increased abundance and diversity of native species in South San Francisco Bay. In order to create these habitats, the Project must convert existing nontidal submerged salt ponds. The levees around the ponds will be breached to connect the ponds to the estuary and allow tides to vary the water level in the ponds. Most of the ponds are below intertidal marsh elevation (Siegel and Bachand 2000). Thus, the elevation of the ponds must be increased to develop an intertidal marsh. Once established, vegetation helps the marsh develop by trapping additional sediment and providing organic material. As land subsides and sea level rises, sedimentation is needed to maintain the elevation of the marsh relative to sea level. The rate of sedimentation will determine whether and when the project objectives will be met. Natural sedimentation is dependent upon:

- Sediment supply from local tributaries and Bay waters.
- Transport of sediment from the Bay and sloughs into the pond by tidal currents.
- Deposition and retention of sediment in the pond.

Restoration actions have the potential to destroy valuable habitat. One effect of breaching a pond to a tidal slough or Bay is to increase the tidal prism of South Bay and the slough. If the tidal prism increases, tidal velocities must increase. Increased velocity can cause erosion in the

slough and in the Bay (Shellenbarger et al. in review). This erosion may cause loss of existing marsh or tidal flats. An example that is similar to salt pond restoration is marshes in the Medway Estuary that had been enclosed by levees beginning about 1700 and were breached by tides in the 1880s. Recently, the marshes have been accreting while the salt marsh creeks and cliffs and tidal flats have eroded (Kirby 1990).
Another effect of restoration will be to alter the sediment budget of South Bay. Some of the sediment supplied by South Bay tributaries will deposit in breached ponds. To compensate for the loss of sediment to the breached ponds, erosion must increase or the amount of sediment leaving South Bay must decrease. The relative change in erosion and sediment export will determine the extent of habitat loss. Thus, the future sediment budget of South Bay is a key issue that will determine how well the project meets its objectives.

Special Status/Indicator Species (Issue 4). *Not yet prepared*
Hydrology/Water Quality (Issue 6): *Not yet prepared*

<u>Objective 1. Create, restore, or enhance habitats of sufficient size, function, and appropriate structure to:</u>

<u>Objective 1B. Maintain current migratory bird species that utilize existing salt ponds and associated structures such as levees. (based on Key Issues 5 and 6)</u>

Maintaining Migratory Bird Species (Issue 4). San Francisco Bay contains the most important salt pond complexes for waterbirds in the United States, supporting more than a million waterbirds through the year (Accurso 1992; Page et al. 1999; Takekawa et al. 2001). Single day counts of waterbirds in the salt ponds during winter months can exceed 200,000 individuals (Harvey et al. 1992), and single day counts during peak spring migration have exceeded 200,000 shorebirds in a single salt evaporation pond (Stenzel and Page 1988). The Bay and its surrounding salt ponds are significant habitat for waterbirds including Canvasback (Aythya valisineria) (Takekawa and Marn 2000), Ruddy Duck (Oxyura jamaicensis) (Miles 2000) and a number of shorebird species (Stenzel and Page 1988). Approximately 10% of the federally threatened U.S. Snowy Plover (Charadrius alexandrinus) Pacific Coast population breeds at San Francisco Bay, mainly in the South Bay salt ponds (Page et al. 1991).

At issue here is the potential effect of the restoration of the 15,000 acres of South Bay salt ponds recently acquired by state and federal agencies to other habitat types, particularly tidal marsh habitat. Despite the documented importance of San Francisco Bay salt ponds to populations of Pacific Flyway waterbirds, few guidelines exist for state and federal wildlife agencies on how to actively manage a significantly smaller amount of salt pond habitat in the South Bay than currently exists to achieve the maximum abundance and diversity of birds using the habitat while keeping maintenance costs and efforts to a minimum. Additionally, little is known on how bird populations will change on the local, regional, and global scales as the salt pond restoration progresses. *(from Warnock et al. 2002)*

<u>Objective 2. Maintain or improve existing levels of flood protection in the South Bay area.</u>
Hydrology/Water Quality (Issue 6): *Not yet available*

<u>Objective 3. Provide public access opportunities compatible with wildlife and habitat goals</u>.

Public Access and Wildlife Compatibility (Issue 9). An important Objective of the project is to provide high-quality recreation and public access compatible with wildlife

(Objective 3). This will include trails, overlooks, and other structures to facilitate access. The science synthesis for Part 1 of Issue 9 addresses our understanding of public access and recreation impacts on the ecological Project Objectives (1A, 1B, 1C). US Fish and Wildlife Service (FWS) and the Department of Fish and Game own the restoration sites. Public access and recreation that can be accommodated consistent with state and federal regulations include hunting, fishing, wildlife viewing, photography, environmental education, and interpretation. While these agencies are dedicated to providing high-quality recreational opportunities as part of the Restoration Project, there is the potential for conflict between the goals of restoring and managing habitat for wildlife and providing public access (Stolen 2003, Delong 2002). It is well-known that human disturbance can have a range of impacts on individuals, species, communities and ecological functions.

This section focuses on understanding the impacts of public access species on these species of greatest concern to the Project: **birds**, including the California clapper rail, California least tern, snowy plover, and migratory and resident waterbirds; **mammals**, including salt marsh harvest mice and harbor seals; **aquatic life**, especially native fish and the native oyster (*Ostrea lurida*); and **vegetation**, especially rare plants and vegetation communities in low, mid-, and high marsh and the upland transition.

<u>Objective 4. Protect or improve existing levels of water and sediment quality in the South Bay and take into account ecological risks caused by restoration.(based on Key Issues 6 and 7).</u>

Hydrology/Water Quality (Issue 6): *Not yet prepared*

Pollutant Effects (Issue 7). Understanding of contaminants in the region has increased greatly in the past decade thanks to several major efforts: the Bay Protection and Toxic Cleanup Program, the Regional Monitoring Program, the Mercury and PCB TMDLs, the CALFED Mercury Project, USGS studies, and US Fish and Wildlife Service studies. Enough knowledge has been gained from these efforts to allow the Project to address contaminant issues in an intelligent manner. However, many questions still remain, especially with regard to mercury, which is probably the water quality topic of greatest concern to the Project. An adaptive management approach, as prescribed by the Mercury Strategy developed by CALFED (Wiener et al. 2003), will allow the Project to continue to gain understanding and better manage water and sediment quality as it proceeds.

<u>Objective 5. Implement design and management measures to maintain or improve current levels of vector management, control predation on special status species and manage the spread of non-native invasive species.</u>

Invasive and Nuisance Species (Issue 8). The purpose of this report is to discuss the role of invasive species and other nuisance species with respect to the objectives of the restoration including a discussion of how design and management measures can maintain or improve current levels of vector management, control predation on special status species and manage the spread of non-native invasive species. Without adequate control and prevention measures, invasive and nuisance species could ultimately hamper or ruin restoration efforts through displacement of desired species and prevention of suitable ecosystem establishment, prevention of physical restoration processes, or loss of special status species post-restoration. Many invasive and nuisance species are adapted for rapid colonization of disturbed areas, can compete with or directly impact special status species, disrupt the natural food web, cause harm to humans, or have a structural impact on restoration structures. These characteristics make these species difficult to control in the restoration environment and make them likely to impact post-restoration ecosystems.

<u>Objective 6. Protect the services provided by existing infrastructure (e.g. power lines).</u>
Infrastructure Effects (Issue 9). *Not yet prepared*

V. Identifying Preferred Performance Standards and Measures for Restoration Progress

As noted above, performance standards and measures in the Science Plan will come from the Syntheses. Performance standards are the *restoration targets*, based on scientific data, for successfully achieving Project Objectives. Performance measures are *parameters or metrics* used to assess progress toward the restoration targets. While the literature can provide some insight into appropriate standards and measures, data from reference sites and ongoing restoration projects must also be collected to produce feasible and ecologically-valuable restoration targets for a particular region.

These literature-based performance standards and measures will be useful in:

- developing a scientific analysis of Project Objectives.
- the Record of Decision to help set Project "success" standards and measures to assess progress toward those standards.
- evaluating Alternatives for their ability to achieve Project Objectives.
- developing the Adaptive Management Plan.
- guiding applied studies that should be conducted to improve performance standards.

The information compiled in Table 3 was taken verbatim from the Science Synthesis summaries.

Table 3. Preferred Performance Standards and Measures from the Science Syntheses

Project Objective	Performance Standards	Performance Measures
1A and 1C: Improve ecosystem functioning; promote restoration of special status species and overall biodiversity	None provided for Sediment Management (Issue 2). Landscape/Habitat Change (Issues 1 & 3) * An analysis of the historical form and structure of South Bay landscapes, habitat mosaics, and their component habitats may provide a basis for developing landscape and habitat targets for the Project. * The early salt works of South Bay might serve as a model for restoration and maintenance of salt ponds. • The historical distribution of tidal flats and marshland might serve to guide the overall future distribution of restored tidal habitats in South Bay. Special Status/Indicator Species (Issue 4): *Not yet prepared* Hydrology/Water Quality (Issue 6): *Not yet prepared*	Sediment Management (Issue 2): * Deposition rates and volumes in breached ponds * Breached pond elevations * Vegetation colonization in breached ponds * Erosion of slough channels * Change in existing marsh area * Change in mudflat area, elevation, and volume * Ecosystem function of ponds, breached ponds, sloughs, and mudflats Landscape and Habitat Change (Issues 1 & 3): * Compare size-frequency distribution of historical and restored patches * Patterns of habitat isolation and association. * Total high tide edge and low tide edge to indicate habitat change at the landscape scale. * A similar measure could be used to track changes in salt pond and other lentic habitats. In this case, the edge of the ponded area would be measured. Special Status/Indicator Species (Issue 4): *Not yet prepared* Hydrology/Water Quality (Issue 6): *Not yet prepared*
1B: Maintain current migratory bird species	Migratory Bird Diversity (Issue 5): *Not yet prepared* Hydrology/Water Quality (Issue 6): *Not yet prepared*	Migratory Bird Diversity (Issue 5): *Not yet prepared* Hydrology/Water Quality (Issue 6): *Not yet prepared*
2: Maintain or improve levels of flood protection	Hydrology/Water Quality (Issue 6): *Not yet prepared*	Hydrology/Water Quality (Issue6): *Not yet prepared*

3: Provide wildlife-compatible public access	<u>Public Access and Wildlife Compatibility</u> (Issue 9): Performance standards for species behavior, distribution, abundance and diversity, as well as ecosystem function targets, should come from Issues 1, 2 and 3. Performance standards for public access and recreation will be developed by the PMT, Stakeholders and Science Team.	<u>Public Access and Wildlife Compatibility</u> (Issue 9): * flight distance of individuals, * activity budgets of individuals, * species diversity and abundance, * nesting and breeding success, * predation rates, * presence/spread of predators & non-native species, * area of vegetation trampled, * amount of erosion due to off-trail excursions, * numbers of recreationists & visitors and their activities, * amount of trash improperly disposed of, * numbers/length of "social" trails, * incidences of wildlife feeding/numbers of animals approaching visitors for food * number of trail users and activities * measurements of public satisfaction with public access
4: Protect/improve existing levels of water and sediment quality	<u>Hydrology/Water Quality (Issue 6)</u>: *Not yet prepared* <u>Pollutants</u> (Issue 7): As no parts of the Estuary will be entirely free of contaminants, the reference condition for contaminants may be sites with relatively low concentrations. A review should be performed to determine whether restoration targets can be established based on existing data. If not, the Project should perform additional sampling of relatively clean habitats. The Regional Water Quality Control Board may establish restoration targets based on other criteria.	<u>Hydrology/Water Quality (Issue 6)</u>: *Not yet prepared* <u>Pollutants</u> (Issue 7): * Food web monitoring is an essential performance measure for adaptive management of restoration in the Estuary, as prescribed by CALFED's Mercury Strategy (Wiener et al. 2003). * Fish monitoring is especially important for mercury. Other types of monitoring are important for determining the impacts of other contaminants. Performance measures would include: * concentrations of mercury and other contaminants in the food web (fish, bird eggs, seals); * general health assessments of key species and communities;

		* toxicity testing would be a way of screening for potential effects of current use pesticides and emerging contaminants; and contaminant concentrations in water and sediment.
5: Manage invasive and nuisance species	<u>Invasive and Nuisance species</u> (Issue 8): * Decisions as to restoration targets and performance measures must be species specific. Fundamental questions that must be answered for each of these species include: --Does the species cause significant adverse impact on the native, natural environment? --Will control and eradication result in a measurable improvement in the natural environment or can other mechanisms be used to ameliorate the impact of the species on the environment? --Are there control and eradication methods available, effective, cost-effective, and socially acceptable? --At what level must control be enacted–towards complete eradication, limitations on distribution, or sustained, but low populations --Are there institutional mechanisms available to assure long-term control?	<u>Invasive and Nuisance species</u> (Issue 8): * A decision matrix should be developed that then focuses on the appropriate level of control for each species as well as an evaluation of alternative measures (other than control) that might be set for the restoration project.
6: Protect services provided by infrastructure	<u>Infrastructure (Issue 9, Part 2)</u>: *Not yet prepared*	<u>Infrastructure (Issue 9, Part 2)</u>: *Not yet prepared*

VI. Assessing Our Predictive Abilities

Predicting restoration outcomes requires tools and data analysis methods that provide acceptable levels of predictive certainty. Such predictive tools include models and statistical methods. The purposes of this section are to give input to the Project Management Team and Consultant Team on:

- most useful tools currently available for short-term and long-term modeling of:
  - landscape, pond complex, and pond level scenarios,
  - bird use in restored tidal marshes and managed ponds,
  - special status species responses to restoration and management actions,
  - flooding potential.
- tools and research needed for more accurate prediction of restoration outcomes,
- the extent to which an issue can be predicted using any type of available tool.

Tools for predicting outcomes are specifically needed in developing Project alternatives, predicting Phase 1 restoration outcomes, and predicting long-term restoration outcomes. According to the Synthesis authors, here is a summary of tools to predict restoration outcomes for the Project Objectives.

<u>Objective 1A and 1C. Improve ecosystem functioning; promote restoration of special status species and overall biodiversity</u> (Issues 1, 2, 3, 4, 6)

Landscape/Habitat Change (Issue 1 & 3). The proposed approach to predict the effects of ecological restoration relies on hydro-geomorphic models to estimate the rate of habitat development, and models of wildlife movement and survival to predict ecological endpoints, such as species composition and population density. The uncertainty of near-term geomorphic outcomes for any given set of starting conditions can be improved by further empirical studies of the demand of intertidal habitats for suspended inorganic sediment, how this demand varies in time as habitats evolve, and how supplies compare to demand. The uncertainty of geomorphic outcomes grows as the forecasts extend into the future because changes in the climatic, geologic, and land use processes that ultimately control sediment and water supplies cannot be exactly known. Even with the best possible models of habitat response to changes in water supply and sediment supply, conditions at the 50-yr Project horizon probably cannot be known well enough to map. There are no sources of data to calibrate models for the response of habitats to climatic changes that are unprecedented in the record of habitat evolution in this region.

Adaptive management of phased implementation of broad restoration guidelines may be the best tool for dealing with the near-term uncertainty that can be resolved with more data and the long-term uncertainty due to changes in habitat controls that cannot be exactly known. Each phase of restoration might be designed to answer questions about formative processes and ecological responses that reduce the uncertainty of subsequent phases. This adaptive approach is likely to extend the life of the Project to accommodate research and adjust the guidelines.

One advantage to this adaptive approach is that it eliminates the need for a Project horizon. The 50-yr horizon that has been adopted by the Project bears no relation to any known periodicity or rate of natural processes or known administrative cycles except the planning period for projects funded through the federal Water Resources Development Act (WRDA). Another advantage is that it affords the Project time to adjust to unforeseeable changes in habitat controls, restoration constraints, or opportunities. A related advantage is that the phased adaptive approach could enable better integration of the Project with local watershed management initiatives, such that the Project has a greater chance to influence the upland supplies of water and sediment, and to improve the overall health of the South Bay Ecosystem.

The tools available for predicting sediment transport and geomorphic response to restoration actions are much less accurate than hydrodynamic or hydrologic models. While numerical modeling will be very important for comparing the relative outcomes for different restoration scenarios, we expect that the uncertainty in predictions of how long establishment of tidal marsh will take or how much erosion of mudflats will take place will not be small enough to ensure that the selected scenario will attain the goals of the Project. For this reason the Project must be designed to respond to adaptive management. For adaptive management to succeed, the Project needs to focus efforts on determining the best ways to monitor whether the project is proceeding as predicted, including detecting changes in bathymetry and sediment cycling, determining what levels of change in these parameters is acceptable, and distinguishing between change caused by the project and other sources of change.

Sediment Management (Issue 2). Specific suggestions for predictive tools are given below and application of multiple approaches is often the best way to reduce uncertainty.

- *Sediment supply from tributaries:* Continued or expanded measurement of sediment supply from tributaries and adding or transferring measurements into the tidal reaches of channels closer to the ponds would improve our database and thus predictive capability.
- *Sediment supply to ponds from Bay:* Numerical models, similar to those developed for other restoration projects in San Francisco Bay (e.g. Bair Island, Napa/Sonoma marsh) are used to predict sediment supply. Field data are needed to calibrate and validate the models to reduce uncertainty.
- *Sediment loss to the Ocean:* Multidimensional numerical models are the best predictive tool available. Field data are needed to calibrate and validate the models to reduce uncertainty.
- *Transport of sediment to ponds:* Multidimensional numerical models are the best predictive tool available. Field data are needed to calibrate and validate the models to reduce uncertainty. Such measurements greatly improved our understanding of the Napa/Sonoma marsh sloughs (Warner et al. 2003) and provided data for developing models used to design the restoration.
- *Deposition at restored sites in South Bay:* Numerical models are the best predictive tool available. Zero-dimensional models that calculate deposition from an average sediment concentration have reasonably predicted deposition at restoration sites (Krone and Hu 2001). Field data are needed to calibrate and validate the models to reduce uncertainty.
- *Vegetation colonization at restored sites in South Bay:* The empirical observations that have been developed for San Francisco Bay can be used to predict future vegetation colonization. The behavior of invasive species is uncertain and perhaps not predictable.

Geomorphic evolution, in response to tidal prism change, may be predicted with empirical relations and numerical models. Detailed surveying of breaches, adjacent sloughs and mudflats, and elevated marsh would improve empirical relations, if done with appropriate spatial and temporal density. Monitoring of geomorphic responses to breaches would also provide data for development and testing of numerical models. Decadal geomorphic simulations in estuaries are not as well-developed as hydrodynamic simulations at the tidal timescale.

Special Status/Indicator Species (Issue 4). *Not yet prepared*
Hydrology/Water Quality (Issue 6). *Not yet prepared*

Objective 1B. Maintain current migratory bird species (Issues 5 and 6)
Migratory Species Diversity (Issue 5). *Not yet prepared*
Hydrology/Water Quality (Issue 6). *Not yet prepared*

Objective 2. Maintain or improve levels of flood protection (Issue 6)
Hydrology/Water Quality (Issue 6). *Not yet prepared*

Objective 3. Provide wildlife-compatible public access

Public Access and Wildlife Compatibility (Issue 9). Predicting impacts to species and ecosystems from human disturbance is extremely difficult. Predictions are hampered by the difficulty in distinguishing between variations resulting from human impacts and those due to natural processes. In addition, animal responses to impacts vary based on a large number of factors including: type of disturbance, duration and speed of disturbance, distance to the disturbance, the movement pattern of the disturbance, location, time of day, season, year, weather, the animal's need for food and cover, reproductive status, experience with past disturbances, and other ecological and physiological factors. Because wildlife responses are influenced by so many variables, data gathered in any particular area or at any particular time are not predictive of animal responses elsewhere or even at the same place at a later date (Rodgers and Schwikert 2003). Wildlife responses to human disturbances are not uniform or consistent (Hammitt and Cole 1998).

Currently, studies of human disturbance use statistical methods as the primary tools to assess disturbance effects, such as t-Tests, regression, ANOVA, CANOVA, MANOVA and non-parametric techniques for non-normal data such as the Mann-Whitney U-Test. Rodgers and Schwikert (2003) recommend stimulus-response experiments to determine when and how individuals respond to different disturbances. But, they state that responses are so unpredictable that "local data should be collected to calculate site-specific buffer distances' to prevent disturbance; "conservation personnel should monitor changes in species composition at regulated sites to adjust buffer distances to reflect the presence of new, more sensitive species"; and buffer zones should be evaluated periodically to determine their effectiveness and corrective measures taken based on data from control sites or sites before disturbance. Given these recommendations, modified Before-After-Control-Impact (BACI) studies (Underwood 1994) should be used to evaluate the effectiveness of all protective measures, evaluate wildlife responses in previously inaccessible areas, and provide greater power in separating natural variation from human-caused responses. Such studies may produce greater predictive capabilities.

Objective 4. Protect/improve water and sediment quality (Issues 6 and 7)

Pollutant Effects (Issue 7). In the past few years the first steps have been made to begin to develop a capacity to predict regional trends in contaminant concentrations in the South Bay for the next 50 to 100 years. Studies have also been performed or are planned that are beginning to delineate processes and patterns in the Estuary and its wetlands and provide the foundation for a predictive capacity. However, our present ability to predict the impacts of the Project on contaminant cycling in South Bay is weak due to a lack of information on contaminant cycling and distribution. Empirical monitoring and research guided by model development will be the way to continue to develop a predictive capacity and reduce uncertainty. Tools that are needed include:

- a conceptual understanding of mercury cycling in Bay wetlands that allows prediction of mercury accumulation in restored habitats, including different subhabitats within wetlands;
- a model and sediment budget that accurately describes sediment mixing and erosion in the South Bay; and
- a long term program of monitoring and research that assesses contaminants prior to, during, and after each restoration project.

Hydrology/Water Quality (Issue 6): *Not yet prepared*

Objective 5. Manage invasive and nuisance species (Issue 8)

Often the occurrence of an invasion is not noticed until it is too late to take action to control the species. In many instances, the scientific investigation focuses on the effect of the invasion rather than how to control or remove the invasive species. This is often a requirement of the regulatory agencies in that a justification is required in order to implement the sometimes temporary, but destructive, environmental impacts and to fund the costly control methods. In addition, persistence, coordination, and long-term funding is usually required. In only a few causes such as the *Caulerpa* invasion in a few coastal lagoons of southern California (ref) and the recent invasion and control of *Spartina alterniflora* in Bolinas and Tomales Bay has rapid eradication followed initial observations of the invader.

The same is true for nuisance species with the exception that they have usually been present in the environment for a long period of time and it is usually a combination of human presence, urbanization, and proximity to suitable resources (including prey) that create conditions where these species can be detrimental to natural habitats and their occupants.

Controlling the effects of these invasive and nuisance species on the environment falls into two primary categories: institutional and scientific. Institutional controls relate to legislative action on non-indigenous species, regulatory controls on new introductions, and development and coordination of government agencies in control and eradication programs. Much has been written on institutional controls (US Congress, 1993). While certainly important and vital to reducing the impacts of these species, further discussion of these controls are not relevant to this report.

While scientific knowledge of invasive species often focuses solely on the after affects of the invasion, some predictive tools have been developed. These predictive tools include modeling population and distributional trend analysis and ecosystem models (both conceptual and mathematical) that portray long-term changes resulting from either establishment or eradication of the species. Good examples of such analyses have been completed on *Spartina alterniflora* (Matsumoto 2004, Collins 2002). Likewise, the effects of the invasion of the Asian clam on the food webs of San Francisco Bay have also been documented (Nichols 1990).

The application of modeling to invasive species needs to be more thoroughly developed in order to more effectively communicate the importance of control. Graphic representations of the spread of a species or the diminishment of another native species are useful outcomes of population models calibrated with observations made in the field. It may be possible to include such modeling efforts into restoration experiments to test how sites where active controls are implemented differ structurally and functionally from those areas where controls have not been instituted. In addition, detailed observations and ecosystem modeling for sites where controls are being instituted now should be completed.

Objective 6. Protect services provided by infrastructure (Issue 9). *Not yet prepared*

VII. Identifying Key Uncertainties

The Science Syntheses have identified a number of short- and long-term research and monitoring questions that address important uncertainties. The purposes of these questions are to identify science-based:

- Short-term data needs that could be addressed through applied studies in the planning stage.
- Information that the Consultant Team should collect to characterize "baseline" conditions for the "Existing Conditions" report.
- Long-term data needs that would be addressed through applied studies, including monitoring for Adaptive Management.

In Table 4 gives a preliminary list of these questions. In the final Science Plan, key questions/uncertainties will be divided into short- and long-term questions, will be ranked in priority order, and will be placed under the appropriate Broad Question and Key Issue.

Table 4. Key Questions and Uncertainties

Project Objective	**Key Questions from Science Syntheses**
1A and 1C: Improve ecosystem functioning; promote restoration of special status species and overall biodiversity	Sediment Management (Issue 2): * How much sediment is needed for each restoration alternative? * What will the rate of sediment supply to the restored ponds be? * How will South San Francisco Bay evolve as tides are restored to the salt ponds? * The South Bay Ecosystem should encompass the sources of sediment and water that control the evolution and natural maintenance of the key habitat types. To determine if the South Bay Ecosystem as delimited here meets this criterion, the historical amounts of shoreline progression and retrogression within the Ecosystem might be measured. If no forces within the Ecosystem drive a net loss or gain in shoreline position, and if the advances and retreats by the shoreline are approximately compensatory, then it might be concluded that the shoreline is controlled by changes in sediment and water supplies internal to the Ecosystem. * Project success may depend on phasing restoration to match sediment demand to sediment supply. This approach requires quantifying how the demand for inorganic sediment changes with marsh age and across the developing marsh plain. This could be ascertained by coring through well-developed marshes at varying distances from channels and tidal sources within the selected marshland, developing chronologies for the cores, and subsequently quantifying the changes in amount of inorganic sediment through time. The result would be a three-dimensional map of inorganic sediment demand per tidal marsh drainage system. Once the sediment demand is understood, then potential South Bay supplies can be assessed. Landscape/Habitat Change (Issues 1 & 3): * The South Bay Ecosystem should encompass the sources of sediment and water that control the evolution and natural maintenance of the key habitat types. To determine if the South Bay Ecosystem as delimited here meets this criterion, the historical amounts of shoreline progression and retrogression within the Ecosystem might be measured. If no forces within the Ecosystem drive a net loss or gain in shoreline position, and if the advances and retreats by the shoreline are approximately compensatory, then it might be concluded that the

	shoreline is controlled by changes in sediment and water supplies internal to the Ecosystem. * Project success may depend on phasing restoration to match sediment demand to sediment supply. This approach requires quantifying how the demand for inorganic sediment changes with marsh age and across the developing marsh plain. This could be ascertained by coring through well-developed marshes at varying distances from channels and tidal sources within the selected marshland, developing chronologies for the cores, and subsequently quantifying the changes in amount of inorganic sediment through time. The result would be a three-dimensional map of inorganic sediment demand per tidal marsh drainage system. Once the sediment demand is understood, then potential South Bay supplies can be assessed. Special Status/Indicator Species (Issue 4): *Not yet prepared* Hydrology/Water (Issue 6): *Not yet prepared*
1B: Maintain current migratory bird species	Maintaining Migratory Bird Species (Issue 5): *Not yet prepared* Hydrology/Water Quality (Issue 6): *Not yet prepared*
2: Maintain or improve levels of flood protection	Hydrology/Water Quality (Issue 6): *Not yet prepared*
3: Provide wildlife-compatible public access	Public Access and Wildlife Compatibility (Issue 9): * BACI studies for surface and water trails for shorebirds, waterfowl and harbor seals; * BACI studies for surface and water trails for clapper rails, salt marsh harvest mice and snowy plovers, in large animal population areas or when species have recovered to an acceptable level; * Disturbance effects of landside and water trail recreation on roosting birds; * Water trail effects on harbor seals; * Success of various management methods in reducing or preventing impacts-- methods such as buffer distances, observation blinds, or social carrying capacities; * Changes in public attitudes toward Restoration Project access and recreational uses.
4: Protect/improve existing levels of water and sediment quality	Pollutants (Issue 7): The key questions relate to whether the four hypothesized mechanisms of contaminant impact on the Project actually occur: * the effect of different types of restoration on contaminant exposure in sensitive species; * the effect of restoration on the South Bay sediment budget and long term trends in South Bay contamination; * the sensitivity of target species, such as clapper rails, to contaminants;

	* present levels of contamination in locations to be restored. <u>Hydrology/Water Quality</u> (Issue 6): *Not yet prepared*
5: Manage invasive and nuisance species	* What are the rates of invasion of newly restored habitats by non-indigenous species? * How does invasion by non-native species affect the ecological "assembly rules" of a newly restored habitat? * Can artificial transplantation of native species to a restoration site be effective in altering the influence of the non-native species? * Is there a "low-level" population size or distribution of an invasive species that can be sustained over time without adverse impact on the natural environment? * Are there other mechanisms in a restoration design that can limit invasion, i.e. hydrologic controls, topographic conditions, and/or sediment composition? * Are there biological controls that can be developed to effectively limit invasive species? * What monitoring tools are available to effectively detect invasive species prior to their becoming a problem in the environment?
6: Protect services provided by infrastructure	<u>Infrastructure Effects</u> (Issue 9): *Not yet prepared*

VIII. Making Science-based Recommendations for Planning, Design and Implementation

The Synthesis authors developed a list of recommendations from the literature that will promote the Project Objectives and/or address constraints and reduce potential negative impacts. The purposes of these recommendations are:

- For use as decision criteria in developing Initial Options and Project Alternatives.
- For use in the Record of Decision to support Alternatives, mitigation measures and design.
- To assist in Phase 1 design.
- To provide the public with science-based justifications for Project plan and design feature.

Table 5. Science-based Recommendations for Planning, Design and Implementation

Project Objective	**Key Recommendations from Science Syntheses**
1A and 1C: Improve ecosystem functioning; promote restoration of special status species and overall biodiversity	Landscape/Habitat Change (Issues 1 & 3): * use historical landscapes and their indicative habitat mosaics of all the major habitat types as models for the marsh-pond complexes- for example restore larger ponds I areas of freshwater influence on marsh vegetation * use the existing levees along the historical sixth-order sloughs to demarcate the marsh-pond complexes * do *not* necessarily use the existing levees within the marsh complexes as spatial templates for marsh patches or managed ponds * restore 4th and fifth-order tidal marsh channel networks as the minimum geomorphic marsh unit * fill behind levees to downsize the ponds and provide broad vegetated plains without channels as marsh complex for ponds * fill inboard of peripheral flood control levees to create broad transitional uplands * extend flood control levees only partway through intertidal zone to allow tidal prism to aid in bedload transport *allow tributaries with large sediment yields to form alluvial fans in marshland to create uplands transition * use abandoned sanitary landfills as uplands and plant with oaks and other native trees. * use bedload dredged from reservoirs and channels of all size to fill subsided lands to intertidal elevations and to build upland transition zones * consider using the historical salt works circa 1900 as model for managed ponds, including using windmills to pump and move water Sediment Management (Issue 2): To manage sediments to create desired habitats while preserving existing habitat: * Dredged materials placement to accelerate restoration and reduce new tidal prism * Time breaches (seasonal, tidal) for maximum initial deposition * Phased breaches to increase tidal prism slowly * Locate breaches to minimize damage to sloughs most susceptible to erosion from

	increased tidal prism * Limit additional tidal prism by keeping ponds isolated or developing muted tidal ponds * Temporary or permanent barriers to control which channels have increased tidal prism * Connect adjacent sloughs to create a zone of flow convergence and sediment deposition * Monitor slough and mudflat erosion and alter breaches if necessary Special Status/Indicator Species (Issue 4): *Not yet prepared* Hydrology/Water (Issue 6): *Not yet prepared*
1B: Maintain current migratory bird species	Maintain Migratory Bird Species (Issues 5): The management implications of this study are complex yet several recommendations stand out. * For attracting maximum numbers and diversity of migrating and wintering gulls and shorebirds, ponds with exposed moist soil and shallow water up to about 10 cm deep are recommended. * Deeper water ponds are needed for many of the ducks and divers. * Salinities of ponds need to be maintained in several ranges, especially the range where fish can live (20-60 ppt), and in the range that promotes a high biomass of invertebrate prey important to a wide range of migrating and wintering shorebirds, waterfowl, gulls, and terns. Our results suggest this latter salinity range centers around 140 ppt. * Roosting waterbirds used islands in the middle of salt ponds, and maintenance and creation of island habitat should be incorporated into management plans for salt ponds. Issue 6: *Not yet prepared*
2: Maintain or improve levels of flood protection	Issue 6: *Not yet prepared*
3: Provide wildlife-compatible public access	Public Access and Wildlife Compatibility (Issue 9): To reduce negative impacts of public access on species: * provide adequate buffer distances between people and all wildlife habitat, typically 30 to 100m, depending on the species and time of year; develop buffers based on the most sensitive species; * provide refuges in all habitat types where no recreational activity of any kind occurs; * avoid nesting habitats and other sensitive areas, such as important roosting and foraging sites; trails should be closed seasonally or not exist at all to provide refuges from human

	disturbance; * limit hunting in time and location and provide refuges from hunters; * implement measures to keep people on trails, such as buffer vegetation; * limit the presence of dogs, require dogs be on leash, require poop removal and exclude dogs from most areas; * correctly site trails and access uses to avoid habitat fragmentation and impacts to rare species, especially impacts to high-marsh and transitional habitat for salt marsh harvest mice; * encourage tangential approach to wildlife, and avoid direct approaches;
4: Protect/improve existing levels of water and sediment quality	Pollutants (Issue 7): To reduce potential negative effects of pollutants: * avoid restoration in areas with problematic amounts of pre-existing sediment or food web contamination – detailed surveys should precede restoration projects; * avoid restoration in areas with significant continuing inputs of contaminants from local watersheds; * monitoring and research should be an ongoing part of SBSP restoration for the duration of the project; and * SBSP monitoring should be closely coordinated with other contaminant work in the region being done by RMP, CALFED, and others Hydrology/Water Quality (Issues 6): *Not yet prepared*
5: Manage invasive and nuisance species	Invasive and Nuisance Species (Issue 8): *Not yet prepared*
6: Protect services provided by infrastructure	Infrastructure Effects (Issues 9): *Not yet prepared*

IX. Instituting a Science Structure

Science Structure to Address Science Needs. Achieving the Project's overarching goal--to restore and enhance wetlands in the South San Francisco Bay while providing for flood management and wildlife-oriented public access and recreation--requires a science structure that is able to generate information to assess restoration progress and answer important questions. The Science Structure must set up a process to bring the best available science into the short-term, planning phase, Phase 1 implementation, and the many Project phases that will follow. Therefore, the Science Structure must implement a process to regularly evaluate key questions/uncertainties, produce information to address those questions, synthesize the information and disseminate it, and then begin the process again by reevaluating the key questions. Such a structure is shown in Figure 2.

Basic features of the Science Structure are a Lead Scientist/Science Team who set the science direction, the Science Management function for refining science needs and synthesizing information, and competitive proposal and research functions for generating new scientific information.

- Lead Scientist—This person is responsible for directing the science development process (i.e. other functions listed here), particularly directing data interpretation and ensuring that synthesized data are prepared and disseminated (reported) to the other participants in the Restoration Process, especially the PMT and Stakeholders.
- Science Team—This group, composed of approximately 15 local science experts, is headed by the Lead Scientist. Their functions are to interpret the current information generated by the Project and other information sources to determine the critical questions/data needs that should be addressed through applied studies. They will generate a list of data needs for the current year that will become a call for proposals. They and the Science Managers will assist the Lead Scientist in developing reports interpreting the most current scientific information. Currently, Science Team expertise covers the essential science fields, however, but clear expertise in social science is missing. The Science Team will add a social scientist, perhaps a cultural anthropologist or resource economist, in the next few months.
- Science Managers for Coordination, Research and Adaptive Management—This level in the organization implements the development, synthesis, and dissemination of new scientific information. This will include data management.
    - Science Coordination/Dissemination Function—Responsible for collecting and managing the information generated by the Project itself and from other sources. Will assist in information synthesis/interpretation and providing reports for the Lead Scientist, Science Team, PMT and Stakeholders. Also responsible for setting up workshops, conferences and other venues for collecting and disseminating scientific information.
    - Research Function—Responsible for evaluating critical questions/data needs from the Science Team to determine research questions essential for achieving Project Objectives that are separate from Adaptive Management. Responsible for developing these questions into a format that will become a call for proposals. Will assist in information synthesis and providing reports to the Science Team.

  - Adaptive Management Plan Function—Responsible for implementing the AMP, in particular ensuring the appropriate monitoring and targeted experiments occur at the correct timescales. Responsible for developing AMP questions/ uncertainties into a format that will become a call for proposals. Will assist in information synthesis and providing reports to the Science Team.
- Proposal Award and Management Function—This level is responsible for developing calls for proposals and implementing the call and award process. This is a competitive proposal process; the Lead Scientist, Science Team, Science Managers, and PMT will make the determination on awards.
- Research Function—Work will be conducted by those awarded contracts through the competitive proposal process. All research will be peer-reviewed. Information generated will be provided to the Science Team and Science Managers for review, synthesis and dissemination. Information will be provided to the Lead Scientist/Science Team as part of the basis for determining the next set of key questions and data needs to be addressed by the proposal process.

The Lead Scientist and PMT are taking action to implement this structure by seeking funding to support this expanded science process. In addition, an agency that could act as the proposal manager for 2005 and 2006 needs to be identified. As the funding and administrative support ramp up, the Science Structure and proposal process will be developed in two stages:

- **Stage 1** (at least 2005 and 2006): A competitive proposal process will begin in 2005 to collect data on critical short-term questions, especially those leading to increased knowledge for the Record of Decision and project design. The Lead Scientist and Science Team will identify critical short- and long-term questions that should be the subject of a call for proposals in 2005 and 2006. The Proposal Manager and Science Team will develop these questions into a call for proposals. It will be necessary to hire a Science Coordinator in 2005 to synthesis information and set up workshops/conferences.
- **Stage 2**: The fully developed Science Structure will be implemented when funding becomes available. The full Structure will continue throughout planning and after implementation of Phase 1. After implementation, the proposal process will focus on long-term research questions/uncertainties, as well as Adaptive Management monitoring needs and targeted experiments.

This on-going science development process will result in regular (perhaps yearly) updates to the Science Syntheses. These updates will allow revisions as needed to Key Issues, Key Questions, Performance Measures, Tools Available/Needed, and Recommendations for Planning, Design and Implementation—i.e. most of the content elements of this Science Plan. Figure 1 shows how the Science Structure will work within the Project to synthesize and generate new information. Updated elements will be used as appropriate in Project Milestones (Table 2).

It is important to realize that the Adaptive Management Plan (AMP) will be a central feature of the science program. It will result in monitoring data on restoration progress and data from targeted research focused on key adaptive management questions, all of which will be used to improve current phases and will be applied to future phases. The AMP will be a long-term plan for learning from the restoration project as it proceeds in order to improve management decisions. Thus, the science program will not be complete until the AMP is finalized.

Opportunities for Applied Studies. Research conducted through this process must have a direct relationship to Project decision-making and, therefore, to achieving Project Objectives. The primary goal of research in the restoration process is to develop information for decision-making that reduces uncertainty about critical ecological processes and restoration outcomes. Applied Studies, which are all the types of research needed for this Project, fall into three categories:

Monitoring—This activity is defined as data collection over time designed to track changes in performance measures over time. The performance measures may be chosen to investigate uncertainties or assess progress toward performance standards.

Targeted Experiments—These studies are designed to clarify cause-and-effect relationships for specific Adaptive Management questions.

Research—This work addresses broader research questions concerning the ecological and physical functioning of the South Bay ecosystem or restoration activities. Research may also proactively investigate emerging science and social science issues that could influence restoration outcomes.

Restoration will occur over many years and is divided into three major periods: planning, Phase 1 implementation, and future phases of restoration. Applied studies should begin during the planning phase and will be included in Phase 1 implementation and all phases thereafter.

To develop information for the planning process and beyond, applied studies should take advantage of research opportunities afforded by pilot projects, reference sites and existing restoration sites, both within the South Bay and in other parts of the Bay. These opportunities can be used to collect baseline ecological data for performance standards, assess performance measures and monitoring techniques, test cause and effect links in ecological processes, and reduce uncertainty in predicting restoration outcomes.

Pilot project opportunities during planning include:

- Restoration activities by the Department of Fish and Game at Eden Landing. Restoration at this site directly adjacent to the Project's Eden Landing pond complex will begin in 2005. An important issue at this site is *Spartina alterniflora* invasion and control.
- Breaching of the "island ponds", A19, A20 and A21, to restore full tidal fluctuation as part of the Initial Stewardship Plan (ISP).
- Water management activities for the ISP. Changes in salinity and water movement into and out of former salt ponds allows opportunities to study effects of salinity changes on water and sediment quality and bird communities. Mercury methylation in these ponds may also be a potential research area.
- Alameda Flood Control District Project at Alameda Creek. Changes to Alameda Creek and adjacent wetlands affords the chance to study flood management in restoration projects.
- Pond A8. A number of questions, including pollutant mobilization, habitat management, flood control and salinity changes are at issue around Pond A8 because of its location near Alviso at the downstream end of the Guadalupe River. A working group is expected to be formed in October to explore these issues and the potential for this site to be a pilot project within the next few years.

There are a number of on-going restoration projects in the South Bay and beyond that could provide valuable information on the linkages between restoration actions and results. A few of these projects are restorations at Bair Island, Charleston Slough, Ravenswood Marsh, Hamilton Airfield, Oro Loma, and Sonoma Baylands. Some relevant data have already been collected by Phil Williams and Phyllis Faber at South Bay sites. These data can be valuable reference information for helping to determine performance standards, measures and methods. In the context of the Science Structure, the Science Coordinator is the appropriate person to integrate existing data from other restoration sites into the Science Synthesis information.

Existing reference sites also provide data for performance standards and can be used to understand ecological functioning of mature systems. In particular, data should be collected from a range of sites along a continuum of ecological performance. The San Francisco Estuary Institute (SFEI) has compiled extensive information on the locations of wetland throughout the Bay.

Peer Review. Peer review is a central feature of the science process at all stages. Science-based products from the Science Team will be reviewed by outside experts in the appropriate fields as well as by the PMT and Consultant Team. Important planning and science documents produced by the Consultant Team will be peer-reviewed by the Science Team. Research generated by the Project will undergo peer review before it is synthesized and disseminated for project use.

Currently, the rapid pace of the project means that some work is not receiving complete review. The Consultant Team is moving forward with Science Team review, but timeframes for those reviews are very short. The challenge of short timelines will not change in the planning phase and at times the Consultant Team will need to use Science Team products that have not undergone peer review. Given the need for rapid progress, the goal of this Plan is to lay out a process for bringing the best science into the Project as quickly as possible, while planning for a long-term, iterative process of information generation, peer review and Project improvement.

X. Integrating Science into the Project

Science Structure and Project Management Team Integration. Science input is woven into management decisions throughout the entire process. This integration is first achieved through the Lead Scientist who is a member of the Project Management Team, the day-to-day decision-making body (Figure 2 and 3) which operates by consensus. The Lead Scientist is responsible for bringing scientific information to the PMT from the Science Team and the larger Science Structure. The Lead Scientist will make regular reports to the PMT and Stakeholders on new science and recommendations relevant to Project decision-making. In addition to this procedural integration, science products will feed into reports and other products developed at Project Milestones, as per Table 2. The science products will be regularly revised (perhaps on a yearly basis) to incorporate new information generated by the Project and by other sources. Finally, workshops and conferences will highlight science and policy issues critical to the Project Objectives. PMT, stakeholder and science team members will attend to facilitate integration of science and decision-making.

Science Team and Consultant Team Integration. The content elements of this Plan are designed to be used by the PMT and Consultant Team at Project Milestones in planning and beyond as shown in Table 2.

The Science Team and Consultant Team are working on parallel tracks in the planning process in order to complete a Record of Decision (ROD) and a restoration design for Phase 1 implementation in 2008. Although parallel, the tracks must intersect to produce a ROD and Phase 1 design supported by the best science. The intersection happens in three ways:

1. The Science Team produces products that are used by the Consultant Team in the development of their products. For example, the recommendations in Part V of this Science Plan should be used by the Consultants in developing project Options and Alternatives.
2. The Consultant Team develops documents that the Science Team reviews and provides comments on or, sometimes, a report. For example, a subgroup of the Science Team provided a report to the PMT on modeling strategies proposed by the Consultant Team.
3. The Science Team and Consultant Team work collaboratively on products that, for the benefit of the Project, should be cooperatively developed. One such product is the set of Conceptual Models for the restoration. The Science Team and Consultant Team must use common models that incorporate a strong scientific basis and are grounded in design and engineering realities. The Adaptive Management Plan is another key product that will benefit from both scientific and applied perspectives.

Table 6 shows the interaction of these two teams with respect to products they are developing.

Budget Estimates for Science Support
This section will not be completed for the Draft Science Plan, as it is dependent on science needs and key questions identified in the Syntheses. The final Science Plan will have a cost analysis for important studies needed for this Project.

The **science budget** for the Project has been approximately $1 million/year to support the Lead Scientist/Science Team/ National Science Panel and to perform research to establish baseline conditions and collect some data for critical short-term, planning questions.

Current Costs	
Lead Scientist/Science Team/NSP/Support	$340,000
Monitoring for Baseline Data (USGS)	$600,000

To develop the **Science Structure** discussed in this plan, these positions should be funded:

Estimated Costs in 2005 and 2006 = $670,000/year	
Lead Scientist/Science Team/NPS/Support	$340,000 total
Science Coordinator (1/2 time)	$100,000 ($100/hour X 1000 hours)
Research and AMP Manager (1/2 time)	$100,000 ($100/hour X 1000 hours)
Proposal Manager (1/4 time)	$50,000 ($100/hour X 50 hours)
Other Costs (research assistants, honoraria, specialists)	$80,000 total

The **Applied Studies Budget** will depend on the Key Questions being researched. However, as a first cut, it seems the budget for developing new information should be at least as large as the budget for the rest of the Science Structure.

Estimated Applied Studies Budget for 2005 and 2006 = $700,000/year
(focus on short-term applied studies for planning and top critical key questions)

For 2005 and 2006, as the Science Structure is developed, it is recommended to seek funding for $1.4 million/year for the science program.

In their report from the April 20-21, 2004 meeting, the NSP (2004) recommended that the Project include a science budget of at least 10% of the total project budget per year, which could amount to about $2.5 million annually. Such a science budget seems completely reasonable for a project of this magnitude. However, the PMT and Science Team believe that starting with the smaller budget given above for 2005 and 2006 is beneficial, as it will allow the science program and proposal process to ramp up and relatively quickly award funding for the full amount of the Applied Studies Budget. A smoothly functioning Science Structure and proposal process will demonstrate to potential funders that their grants will be efficiently and effectively used. It is desirable to increase funding to the level of about $2.5 million before the end of the planning phase in 2008. An increased budget in 2007 and 2008 will be especially important for implementing monitoring/targeted experiments for the Adaptive Management Plan, as well as funding long-term research questions.

Of course, if funding is limited, the Science Team and PMT will need to make choices between high-priority questions, which will increase uncertainty in achieving the Project goals. In their analysis of the Greater Everglades Ecosystem Restoration Science Program, the National Research Council (2003) made a comment that applies equally well here: “science funding for studies represents an investment in the knowledge base that will support the restoration over its lifetime.”

References Cited (Sections I, VI and VII only)

National Research Council. 2003. Science and the Greater Everglades Ecosystem Restoration: An assessment of the critical ecosystem studies program. Washington DC: National Academy Press.

National Science Panel for the South Bay Salt Pond Restoration Project. 2004. National Science Panel Meeting, April 20-21. 2004: Summary of Recommendations. Prepared for the South Bay Salt Pond Restoration Project PMT (Project Management Team.

Table 6. Coordination between Consultant and Science Teams

Consultant Team Deliverable/Action	Draft	Final		Science Team Deliverable/ Review Action	Draft	Final	Purpose of Science Team Deliverable
Alternatives Development Framework	6/04	8/6/04		Comments= ST Peer Review	6/22/04	--	
Data Summary Report	5/17/04	7/16/04		Comments	6/17/04	--	
Initial Opportunities and Constraints Report	7/04	8/04		Comments	8/04/04	--	
Comments				Synthesis Reports/ To be Peer Reviewed	9/15/04	12/15/04	Forms basis of Science Plan, for Call for Proposals, for Conceptual Models, for AMP Elements
Comments				Science Plan/ To be Peer Reviewed	9/28/04	3/01/05	Provides plan for increasing scientific knowledge to achieve POs
Comments				Report: Analysis of Modeling Strategy Document		9/20/04	Guides physical processes modeling at all scales
Conceptual Models/Collaboration with ST	9/20/04	2/15/04		Conceptual Models/ Collaboration with CT/To be Peer Reviewed	4/20/04	03/15/05	
Support for Science Team				Adaptive Management Plan Outline/Collaboration with CT	09/28/05	--	
Support for Science Team				Adaptive Management Plan/ Collaboration with CT/To be Peer Reviewed	4/01/05	7/01/05	Directs learning from/ assessing progress of restoration and applying data to management decisions
Comments				Science-Based Project Objectives/ Internally Reviewed by PMT & CT	11/15/04	01/15/05	Provide scientific justification for POs and identify conflicts
Comments				2005 Key Questions/Internally Reviewed by PMT and CT	11/15/04	1/15/04	Basis for Initial Call for Proposals
Support for Science Team				Call for Proposals/Internally Reviewed by PMT and CT	2/15/05	3/15/05	Begins process of collecting data on top applied studies questions; some will apply to planning stage
				Research Grants Awarded by ST and PMT		5/15/04	Initiates first round of competitively awarded research

Consultant Team Deliverable/Action	Draft	Final		Science Team Deliverable/ Review Action	Draft	Final	Purpose of Science Team Deliverable
Existing Conditions Reports	01/14/05	02/18/05		Comments	01/30/05	--	
Preliminary Project Alternatives Memorandum	12/1/04	01/21/05		Comments	12/15/04	01/07/05	
Comments				Report: Scientific Basis for Alternatives Selection	02/01/04	05/01/05	Provides quantitative metrics for comparing alternatives
Final Project Alternatives Report	07/01/05	09/30/05		Comments	08/01/05	--	
Mercury Technical Memorandum	--	08/13/04		Comments	7/04	--	Provides scientific understanding of Hg Issue
Modeling Report #1 (Set-up and calibration methods)	04/15/05	06/10/05		Comments	05/15/05	--	
Landscape Scale Analysis Memorandum	1/05/05	2/10/05		Comments	1/25/05	--	
Existing FloodDrainage Conditions Report	01/14/05	02/18/05		Comments	01/30/05	--	
Comments				Report: Science Syntheses, Revised for ROD	03/01/05	06/01/05	Provides summary of knowledge that should be included in the ROD
Feasibility Report (50% complete)	07/01/05	–		Comments		--	
Environmental Setting Report	03/25/05	06/25/05		Comments	04/10/05	--	
Preliminary Impact Analysis Summary Memorandum	8/26/05	9/30/05		Comments	09/15/05	--	
Comments				Report: Evaluation of Preliminary Impact Analysis Memorandum	09/30/05	11/30/05	Evaluates scientific basis of impacts analysis; for use in EIR/EIS

<u>Figure 1.</u>
<u>South Bay Salt Pond Science Program in Relation to Project Planning and Implementation</u> {based on NSP (2004) Figure 1}

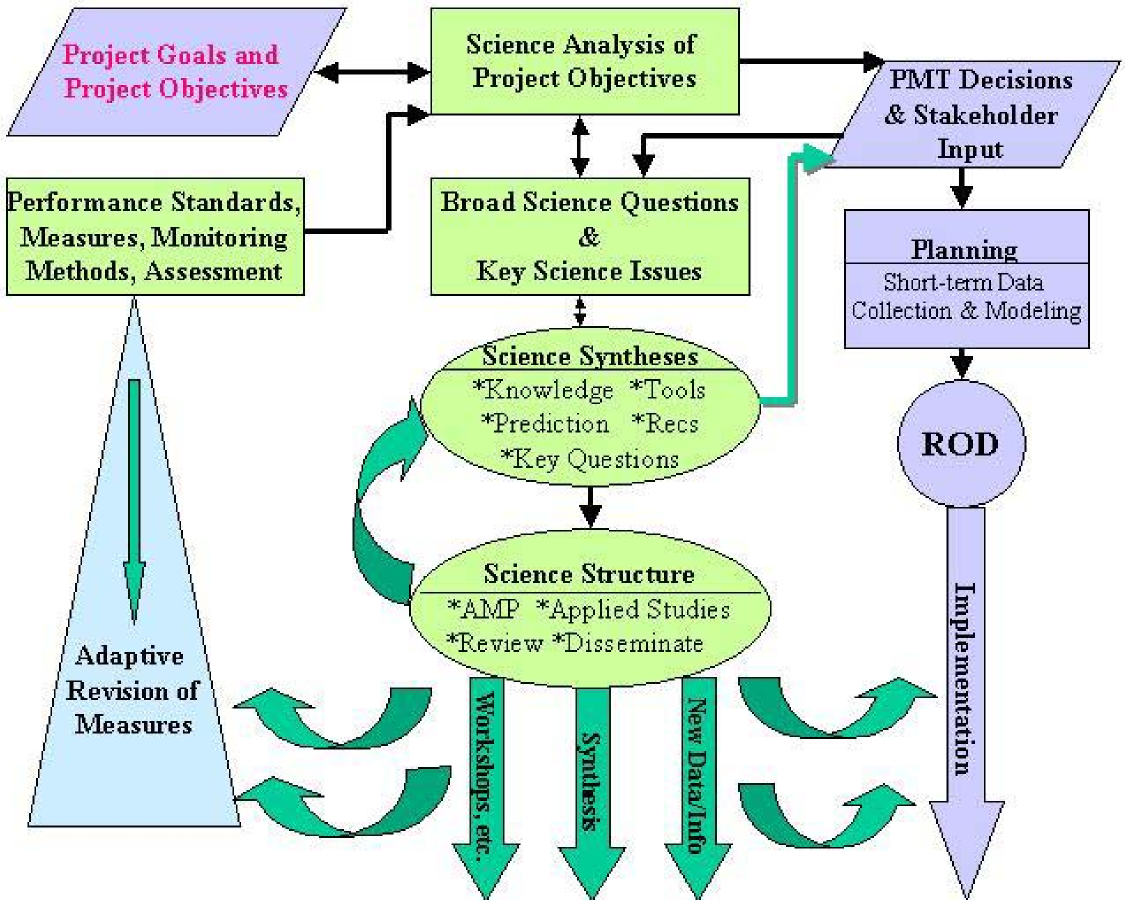

Figure 2.
South Bay Salt Pond Restoration Project Organizational Structure

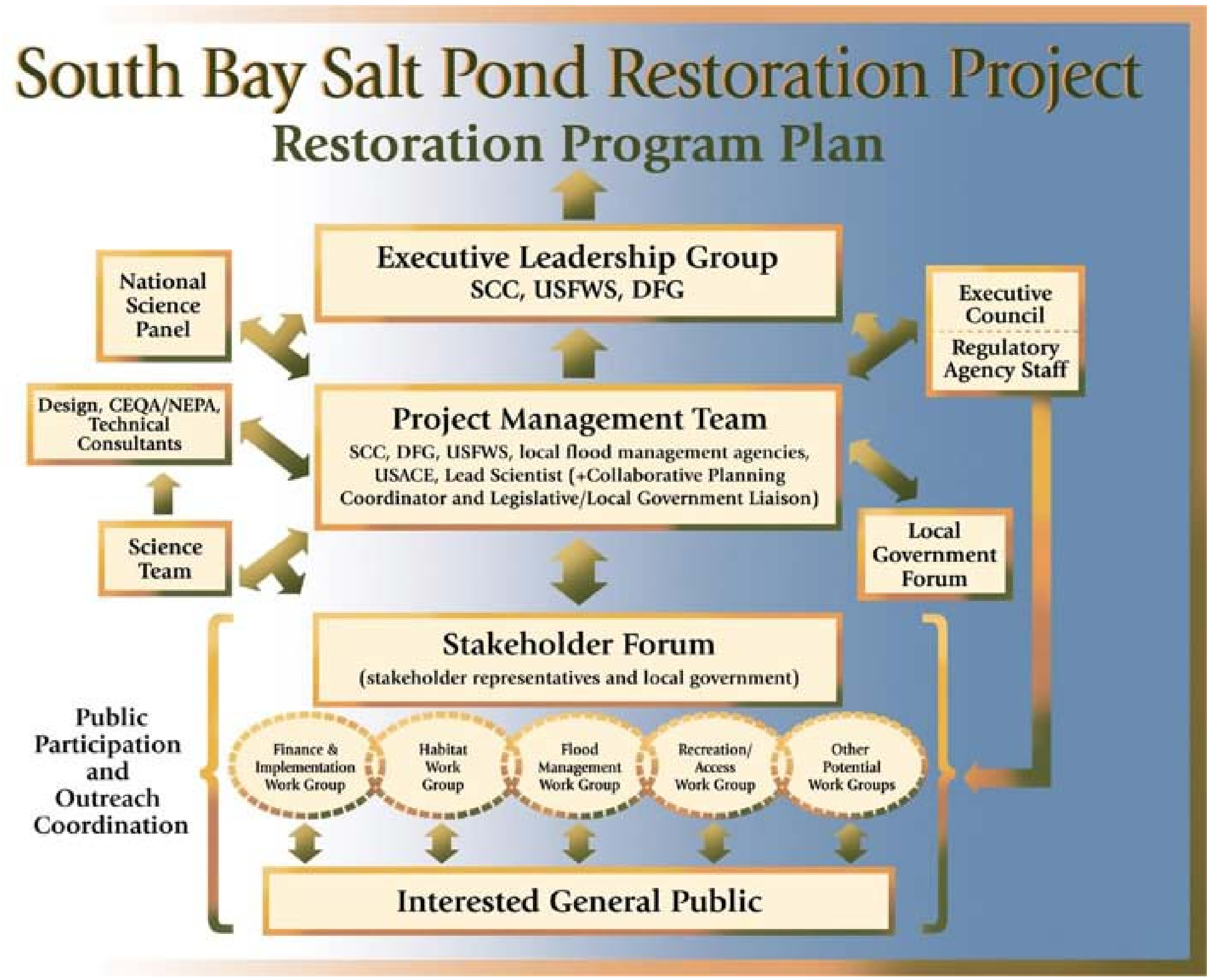

Figure 3.
South Bay Salt Pond Science Structure

Appendix 1. Science Synthesis Authors

Issue	*Lead*	*Support*	*Supporter's Subtasks*
1: Ecosystem Function	Josh Collins	Fred Nichols	Historical changes
		SFEI Staff	All sections
		Kate Schaffer, Aquamarine Research	Fish
2: Sediment Management	Dave Schoellhamer	Jessie Lacy	All sections
		Greg Shellenbarger	
		Neil Ganju	
		Megan Lionberger	
		Mark Stacey	
3: Tidal Marsh/Assoc. Habitats	Josh Collins	SFEI Staff	All sections
		Kate Schaffer, Aquamarine Research	Fish
4: Special Status and Indicator Species	Lynne Trulio	John Callaway	Special Status Plants
		Kate Schaffer, Aquamarine Research	Steelhead, Fish spp., Brackishwater snail
		Howard Shellhammer	Salt marsh harvest mouse
		Rena Obernolte	*Ostrea lurida*
5: Managing Ponds for Bird Biodiversity	Nils Warnock	John Takekawa	
		PRBO Staff	
		Kate Schaffer, Aquamarine Research	Fish
6: Hydrological/Water Quality	Dilip Trivedi	Ed Gross	
		Dave Schoellhamer	
		Mark Marvin-DiPasquale	
7: Pollutant Effects	Jay Davis, SFEI	Mark MD	Mercury
		SFEI Staff	Other pollutants
8: Invasive and Nuisance Species	Mike Josselyn	Fred Nichols	Invertebrate invaders
		Cheryl Strong	Native and non-native vertebrate predators
		Wetland Research Associates Staff	All sections
9: Impacts of Human Activities	Lynne Trulio	Dilip Trivedi	Infrastructure

Appendix 2.
Draft Summaries of Science Syntheses: State of the Knowledge by Key Science Issue

Key Issues 1 and 3:
(1) Maintaining and Improving Functioning of the South Bay Ecosystem and
(2) Restoring tidal salt marsh and associated habitats over the next 50 years at pond and pond-complex levels

For the Science Team of the South Bay Salt Pond Restoration Project

Joshua N. Collins, Ph.D.
Wetlands Science Program
San Francisco Estuary Institute
September 15, 2004

This summary follows from the draft outline of the Synthesis, the Key Issues document for the Project, and the Draft Science Synthesis for Issue 9 by the Science Team Lead. It is a brief description of scientific knowledge relative to a few key questions common to all the Key Issues, based on the larger and more comprehensive review and synthesis of scientific information for Issues 1 and 3.

What is the importance of these Issues as they relate to the Project Objectives?

Issues 1 and 3 cut across all six Project Objectives but pertain most directly to Objective One: create, restore, or enhance habitats of sufficient size, function, and appropriate structure to (A) promote restoration of native special-status plants and animals that depend on South San Francisco Bay habitat for all or part of their life cycles; (B) maintain current bird species that utilize existing salt ponds and associated structures such as levees; and (C) support increased abundance and diversity of native species in various South San Francisco Bay aquatic and terrestrial ecosystem components, including plants, invertebrates, fish, birds, reptiles and amphibians.

Furthermore, the recommended approach and emerging design principles for the Project emphasize deference to natural processes of the lands and waters of the South Bay Ecosystem to meet the objectives with minimal infrastructure and management.

Meeting the Project objectives according to the design principles will require scientific understanding of the relative influence of natural processes and land use on the quantity and quality of all the major types of habitat that span the tidal gradient from adjacent uplands and fluvial systems through the intertidal and diked baylands to the subtidal areas of South San Francisco Bay. This broad view is required because in essence the Project occupies the transition zone between terrestrial and aquatic-estuarine systems and thus some portion of the ecological services of the Project depend on adjacent processes, and some of the adjacent processes will be affected by the Project.

What do we know about these issues as they relate to the Project?

This synthesis organizes the pertinent information into a spatial hierarchy starting with what is known about the nature of the prominent physiographic elements of the major habitat types, and scaling up through the habitats to typical landscapes and the South Bay Ecosystem as a whole. Special attention is given to the ecotones between major habitat types because of their influence on overall biological diversity. The history of land use is laid over the knowledge of natural habitats and landscapes to resolve the influence of people on existing conditions. The layering of natural and human history on the spatial hierarchy yields a synthesis of understanding about the ecosystem and its characteristic landscapes (Issue 1) as well as the habitat types and their physiographic elements (Issue 3).

Definition of the South Bay Ecosystem. The South Bay Ecosystem is the term being applied to the geographic limits of natural processes and land use that more or less directly control the likelihood that the Project will meet its objectives. Since Project success will rely on adequate supplies of inorganic sediment and water from the estuary and from local watersheds (Knebel et al. 1977, McKee et al. 2003), the ecosystem will have a terrestrial-fluvial as well as an estuarine-tidal extent.

There is no existing definition of the South Bay Ecosystem for the Project to adopt. To encompass the geographic processes that are likely to control the performance of the Project, the South Bay Ecosystem should probably be defined as the South Bay and its adjacent watersheds. Recent efforts through the Sate of California (CalWater), the National Hydrologic Database (NHD), the Santa Clara Valley Water District, and the Regional Monitoring Program for Trace Substances (RMP), have produced consistent maps of the outside boundaries of South Bay watersheds that can serve to delimit the terrestrial-fluvial extent of the South Bay Ecosystem. However, according to the California State and National Boards of Geographic Names, South Bay is not an official place. There is therefore no state or federal map identifying the limits of South Bay. A number of early studies generally referred to the extent of tidal excursion South of the San Francisco Bay Bridge as South Bay (e.g., Conomos 1979, Hollibaugh 1996), whereas other studies commonly identify the San Bruno Shoal as an important hydrodynamic boundary between South Bay and Central Bay (e.g., Powell et al. 1986, Jassby 1996). These bay boundaries are derived from consideration of estuarine processes only, without regard to the adjacent terrestrial or fluvial systems. The Baylands Ecosystem Goals Project (Goals Project 1999) refers to the boundaries of local watersheds and the natural morphometry of the Estuary to demarcate South Bay from Central Bay. A line drawn across the Estuary between Coyote Point on the west side and Hayward Landing on the east side approximates the northern limit of South Bay according to the Goals Project. This line is far south of the San Bruno Shoal, however. Considering the fluvial and tidal arguments together suggests that the northern limit of South Bay might extend across the estuary just north of the San Bruno Shoal, and connect to the northern boundaries of the Colma Creek Watershed on the west side, and the southern boundary of the San Leandro Creek Watershed on the east side. Further discussion with the Science Team of the Project is needed to judge the efficacy of this suggested South Bay Ecosystem boundary.

Sedimentary and hydrologic formative and maintenance processes of South Bay habitats, especially tidal marshland. Understanding about the formative and natural maintenance processes varies among the major habitat types. Only disturbed remnants of most types exist, and knowledge about their nature depends on interpretations of diverse kinds of evidence of historical conditions (Atwater 1979, Goals Project 1999). Although the science of Historical Ecology is gaining recognition (Striplen and DeWeerds 2002, Balze 2003, Swetnam et al. 1999), and the number of such studies of Bay Area environments is increasing (e.g., Grossinger et al. 2004, Goals Project 1999), few historical ecology studies have advanced into the primary literature.

Vernal pools, wet meadows, sausals. The nature of bayshore vernal pool complexes, bayshore wet meadows, and sausals (non-riparian stands of willow) is not understood in detail. The emerging understanding about these habitat types is that they occupy different positions along the gradual gradient between the upper intertidal zone and adjacent valley bottoms or broad alluvial fans. The formation and maintenance of these habitat types apparently depends on available groundwater. They tend to be distant from fluvial influences and are largely controlled in size and extent by patterns of groundwater emergence. Sausals correspond to the contours of groundwater emergence low on fans or alluvial plains.

Vernal pool complexes formed on the very fine-grain alluvium at the ancient lateral boundaries of fans. Wet meadows were associated with very high water tables, emergent groundwater, and natural artesian springs in valley bottoms and as the upland matrix of vernal pool complexes (Collins et al. 2004). There is also evidence that sausals were managed by the Ohlone for medicinal and other purposes.

Salinas, marsh pannes, and marsh ponds. These are lentic intertidal elements of tidal marsh habitat. They are distinguished from each other by their formative and maintenance processes. The understanding of these processes is mostly represented by unpublished reports and theses, abstracts of data from scientific symposia, and restoration project designs. Nevertheless, the understanding seems robust (Collins et al. 2004).

Salinas are very shallow lentic features that parallel the backshore of tidal marshland within the extreme upper limit of tidal excursion. They apparently form due to accumulation of salts at very poorly drained areas of the tidal marsh plain far from any fluvial or tidal channels. Salinas are largest and most common under very saline regimes, but small examples also exist in brackish regions of the estuary (Collins et al. 2004).

Marsh pannes are defined as the lentic features that form on broad drainage divides of tidal marsh plains between drainage networks away from the backshore and foreshore. Different formative processes have been identified for analogous features in different climates (Yapp et al. 1917, Kesel and Smith 1978, Pethnic 1974, Pethnic 1992, Christie et al. 2002, Ewanchuck and Bertness 2004). In all cases the feature is sustained by the entrapment of salts and persistent saturation that inhibits plant growth. The feature must also be isolated from abundant inputs of suspended sediment that would fill the feature. The immediate margins of marsh pannes are usually the highest places in marshes. Analysis of time series aerial images plus sediment cores show that pannes in Bay Area marshes disappear if connected to tidal channels, apparently because subsequent drainage and sedimentation promotes plant colonization (Collins et al. 1987). The formation of these pannes is less understood, but may relate to differential rates of peat production across the marsh plain, due to spatial variations in primary production, which in some places results in isolated-saturated topographic lows, wherein the vegetation dies and can't recover (Collins et al. 1987). Marsh pannes vary in number and size in relation to tidal salinity regime, with fewer but larger pannes existing under fresher conditions (Grossinger 1995). This pattern is probably influenced by the combined effect of salinity and hydroperiod on the vertical distribution of vascular plants (Collins and Foin 1993). As regimes freshen, vascular plants grow absolutely lower in the intertidal zone (Harvey et al. 1977, Atwater and Hedel 1976, Jones and Stokes et al. 1979, Collins 2002), and thus encroach into the heardward reaches of tidal marsh drainage networks, shortening them and causing the adjacent drainage divides of the marsh plain to broaden, such that larger pannes can form.

Marsh ponds are defined as the areas of partially impounded high tide water connected to the end of tidal marsh channels. Unlike marsh pannes, the ponds are strongly associated with marsh channels. The formative processes of these features are not known, but may relate to the nature of flood flows into marsh drainage networks. It has been observed that marsh pannes exist between dendritic channels networks wherein the channel cross-section and tidal range decrease headward from the tidal source (Collins et al. 1986), but that marsh ponds exist at the ends of relatively large channels that do not decrease much in width, and within which tidal range is amplified in the headward direction (Siegel 2004). The marsh ponds may therefore represent a localized basin of relatively large water exchange.

Salt ponds. Salt ponds are defined as natural salinas, pannes, ponds or unnatural intertidal impoundments that are managed to harvest salt. The modern industry of salt production in South Bay can be traced to the Ohlone who managed salinas for salt that they traded within and outside the region. Salt ponds were a feature of South Bay prior to Euroamerican contact. The large Crystal Salt Pond of historical times was probably a natural salina or set of salinas modified by the Ohlone to enhance salt production. Historical maps of this pond show the remnants of natural levees along drowned channel networks of pre-existing marshland (Collins et al. 2004).

Tidal marsh channels. Tidal marsh channels are the most thoroughly studied element of tidal marsh habitat. Early studies in the Bay Area have focused on the nature of tidal channel formation (Pestrong 1965, Pestrong 1969, Pestrong 1972), especially with regard to critical sheer stress, and this line of study continues (Kamman Hydrology and Engineering 2004, Siegel 2002).

More work has been done on the hydraulic geometry of tidal channels, meaning the relationship between tidal prism or drainage area and channel form in cross-section, profile, and plan view, usually in the context of designing channels for restoration projects (e.g., Collins et al. 1987, Collins and Orr 1988, Coates et al. 1989, PWA 1995, Siegel 1993). The typical log-log plots of hydraulic geometry reveal large variability around trends of increasing cross-section with tidal prism. The variability may be due in part to the pooling of data for restoration projects and remnant natural systems varying in developmental stage or response to hydro-modification. The dataset also under-represents fresh and brackish marshes and the largest (6^{th}-order) and smallest (1^{st}-order) systems in the region. For the systems studied, the results indicate that channels with base elevations above low tide gain cross-sectional area in the downstream direction due mainly to increases in depth. Further downstream, where base elevations are below low tide, the gains in area are mainly due to increases in channel width. Thus, the larger channels (4^{th} or 5^{th}-order) are U-shaped in cross-section and seldom dewater during ebb tide, whereas the smaller channels are V-shaped and usually dewater completely.

Natural levees are ubiquitous elements of the larger natural tidal marsh channels (Atwater 1979, Collins et al. 1987). These levees are higher along the outside of meanders, where sediment-laden flow is superimposed, and the levees decease in elevation in the upstream direction. Thus, the channel viewed in profile increases in depth and width downstream, while the elevation of the channel bank decreases upstream. The smallest channels furthest from the tidal source usually lack natural levees.

Tributary channels tend to grade abruptly to the base elevations of their receiving channels, such that smaller channel enter larger channels as “hanging beds.” What controls the elevation of these hanging beds is not known.

A few studies in this region have focused on tidal flow through marsh channels (Leopold et al 1993, Siegel 1993, Warner et al. in press, Siegel in press). As noted above in the discussion of marsh ponds, tidal maxima and range can apparently increase or decrease headward within the drainage network of a marsh, depending on the overall channel length, cross-sectional form, and branching. The tidal range can be amplified at the end of large channels with few tributaries. The range can also be amplified due to increases in tidal maxima at zones of barotropic convergence, where the flood flow from two sources is combined (Collins et al. 1987, Warner et al. in press). This happens along the middle reaches of a “looped” channel that is open at both ends to tidal inflow. The convergence happens within an elongated zone rather than a point because of the diurnal inequality of the high tide. If sediment supplies are great enough, the suspended load that is deposited in the convergence zone can lead to division of the channel into two drainage systems with independent tidal sources (Collins et al. 1987).

Fewer studies have examined the transport of sediment in tidal marsh channels. A single longitudinal profile of depth-integrated suspended sediment in a large (5^{th}-order) dendritic system during a flood tide that did not exceed the channel banks revealed a decrease in turbulence and sediment concentration in the upstream direction. It also showed that sediment settled from the upper layers of water, and that the network with its “hanging beds” served to decant the sediment, such that little sediment was carried into the most headward reaches of the drainage network. This was used to explain the lack of levees in the headward reaches (Collins et al. 1987, Leopold et al. 1993). Studies of sediment transport within a newly restored marsh revealed dynamic processes of net inflow and outflow depending on neap-spring differences in tidal amplitude and the evolutionary stage of the marsh plain. During very early stages, channels variously formed and filled, until the marsh plain evolved upward to the threshold for plant colonization (Siegel 2002).

A broad view of the plan form of tidal marsh drainage networks in the Bay Area (Collins et al. 2004) shows that for any channel order average width, meander wave length, curvature, and radius are similar among salinity regimes, but that meander amplitude tends to decrease with increasing salinity. Drainage area increases with salinity for 1st- 4th-order networks, but decreases with salinity for larger systems. And channel density decreases with decreasing salinity. These data are consistent with the observation that broader marsh plains exist in fresher marshlands.

Tidal marsh plain. Studies of the physical nature of the tidal marsh plain have focused on sedimentary processes (Krone 1987, Collins et al. 1987, Culberson 2001, Callaway et al. 1996, Williams and Orr 2002, Siegel 2002), including vertical accretion of tidal marshlands and its inland transgression during Holocene sea level rise (e.g., Byrne et al. 1994, Wells and Gorman 1994). From these studies it is clear that the relative importance of inorganic sediment and organic sediment (i.e., peat production) varies predictably with marsh formative stage and with distance from tidal source. Cores taken through ancient marshes show gradual increases in organic matter as the tidal flat is colonized by vegetation. As the plant cover becomes denser, it functions to filter sediment from the flows of water across the marsh plain, such that the inorganic sediment is trapped near the channel banks. In advanced stages of tidal marsh development, inorganic sedimentation is largely restricted to areas within a few meters of the channel banks, including the channels themselves. At places further from the channels, cores reveal patterns of seasonal and episodic inorganic sedimentation as alterations between organic material in growth position and thinly bedded clay and silt varves. In the middle reaches of very large drainage divides, the pile is essentially organic, indicating very little input of inorganic sediment. Thus, the requirements of marshland for inorganic sediment to keep apace with sea level rise decreases with marsh age and, for well-developed marshland, with distance away from channels mouths and banks. Whether or not the zone of sediment entrapment varies in width with channel order or vegetation type is not known. But for well-developed salt marshes, the maximum width of the zone seems to be about 10 meters (Collins et al. 1987).

Groundwater in tidal marshes. There are few studies of groundwater behavior in tidal marshland of the Bay Area. Most data pertain to a single well or small array of wells for monitoring water quality. Two studies of groundwater behavior in relation to tidal channels show that drawdown and recharge through channel banks is restricted to the zone of inorganic sedimentation on the marsh plain (Howland 1976, Balling and Resh 1983). The logical interpretation is that deposition if very fine silts and clays along the channel reduces the hydraulic conductivity and permeability of their banks and adjoining marsh plain. Measures of near-surface groundwater fluctuations on drainage divides of marsh plains away from channels reveal daily steps in drawn down due to evapotranspiration during neap tides, and daily steps in recharge during spring tides. The average depth of marsh pannes corresponds to the average depth to groundwater below the surface of adjacent marsh plains (Collins et al. 2004). This suggests that the maintenance of marsh pannes is related to the neighboring height of the near-surface water table.

Marsh evolution and dynamics. It is generally accepted that tidal marshes in the Bay Area evolve from tidal flats due to colonization by vascular plants (Byrne et al. 2001, Malamud-Roam 2000, Williams and Orr 2002). The ancient marshes began developing along the shore of the young estuary about 3,000 years BP, after the rate of sea level rise slowed sufficiently to prevent the drowning of intertidal vegetation (Atwater et al. 1979). Most of the historical bayshore adjoined broad areas of shallow bay not subject to great storm surges or very high wave energies, and thus suitable for the formation of retentive environments including tidal flats and marshes (Malamud-Roam 2000). At the time of Euroamerican contact, the open bays of the estuary were nearly surrounded by very broad expanses of tidal flats and even broader expanses of tidal marsh (Goals Project 1999). There seems to be a positive spatial correlation between the extent of tidal flat, the extent of tidal marsh, and the area of fluvial drainage entering the intertidal environment (Collins et al. 2004). This supports other findings that local Bay Area watersheds make important contributions of inorganic sediment to the maintenance of tidal flats and formation of marshes (Knebel et al. 1977, Collins 2001, Malamud-Roam 2004). The large areas of vegetated floodplain that historically existed along all the major rivers entering the estuary through the Delta, plus the sediment entrapment capability of the Delta itself, plus the sandy composition of Suisun Bay sediments, plus the lack of inorganic sediment on marsh plains prior to Euroamerican land uses support the estimates that prehistoric sediment loads coming through the Delta were slight compared to modern loads (Gilbert 1917, McKee et al. 2003), and that local supplies of sediment may have been essential for marsh formation and maintenance.

The evolution of tidal marsh from tidal flat may be rapid, as when a diked area of suitable elevation for plant colonization is breached, or more gradual, as when interactions between plants and wave regimes along the bayshore change the local sedimentary environment in favor of sedimentation. Core data from natural marshes indicate that conversion from natural tidal flat to tidal marsh is iterative and generally slow (Byrne et al. 2001), which further indicates that the historical foreshore of marshland was generally in equilibrium with sediment supply, and thus sediment-limited. Areas of erosion and progression of tidal marsh are clearly evident on the historical topographic sheets of the first coast survey, which predate much land use change, but whether these waxes and wanes of the shoreline were compensatory or a net change was occurring has not been determined.

Studies from outside the region suggest that for any salinity regime the density of channels decreases as the marsh plain evolves upward through the tidal range (e.g., Ahnert 1960, Redfield 1972). Higher marshes obviously have less water to drain, and channel networks tend to adjust in capacity to changes in tidal prism (Leopold and Maddock 1953, Dedrick 1989, Dedrick 1993).

During early stages of marsh formation, the upward development of the marsh plain can outpace sea level rise (Byrne et al. 1994). But as the marsh plain builds upward through the tidal range, the frequency and duration of inundation decrease, and the ability of the channel network to decant suspended sediment increases, such that less and less sediment is delivered to the marsh plain. This accounts for the decrease in marsh sediment density with marsh age (Collins et al 1987). There must also be negative feedback to the marsh plain vegetation, since the rate of organic sediment production also decreases. In the Bay Area, where most of the marshland seldom if ever receives large pulses of sediment, tidal marsh vertical accretion tends to achieve equilibrium with sea level rise. The oldest marshes have continued to build upward at an average rate of about 2 mm per year since their maturity, mostly due to below-ground peat formation, which matches the average rate of sea level rise for the same period (Atwater et al. 1979, Byrne et al. 1994, Mudie 1975, Wells and Gorman 1994). One implication of these findings is that the high elevations of mature marsh plains may not be optimal for plant productivity, and that productivity might increase in response to increases in the rate of sea level rise. Changes in the rate of sea level rise can also influence the salinity regime and thus affect changes in plant species composition on the marsh plain, which in turn can affect its rate of vertical accretion, since the filtering capability and rates of productivity vary between species of marsh plants (Culberson 2001, Byrne et al. 2001).

Marshes that achieve equilibrium with sea level rise are not static. The larger channels (4^{th}-order and larger) migrate so slowly that modern aerial images and historical maps of them overlay almost exactly (Grossinger 1995). But there is a dynamic relationship between plant growth and tidal flows that is manifest as changes in the distribution of smaller channels and marsh pannes (Collins et al. 1987). In the heardward reaches of the smallest channels, tidal velocities are slight, and vascular vegetation tends to accumulate. A ubiquitous process of channel retrogression is sustained by the tendency of vegetation to cover and eventually occlude these small channels (Yapp et al. 1917, Collins et al. 1987). For very large drainage systems (4^{th}- order and larger) in saline marshes, channel retrogression at the ends of some channels tends to be compensated by headward erosion in other channels, such that there is no net change in channel capacity for the system as a whole. The mechanism for this compensation between channel loss and gain is not well understood. In these large systems the ongoing loss of some small channels is evidently insufficient to affect a change in the cross-section of the tidal source; the amount of tidal prism equal to the amount of channel lost is apparently shunted along the hydraulic gradient of the flood flow from the retrogressed channels to other channels that subsequently erode headward to accommodate the increase in tidal prism. The headward erosion of channels can significantly rearrange the drainage systems in their headward reaches by invading and capturing the tidal prism of adjacent systems and marsh pannes (Collins et al. 2004). If this process of tidal prism conservation is real, then it follows that naturalistic systems of 4^{th}-order or larger are minimal to sustain all the ecological and hydrological services ascribed to channels large and small. The drainage area of saline marshland encompassing such systems ranges from 0.5 km^2 (4^{th}-order) to 0.75 km^2 (5^{th}-order). If the same mechanism of tidal prism conservation exists in brackish marshes, then the minimum size of sustainable marsh drainages might be 0.25 km^2 (4^{th}-order) to 1.5 km^2 (5^{th}-order). In any case these values of minimum marsh size would only pertain to large areas of low-gradient marshland. The narrow areas of marshland that attend some large channels and the bayshore are characterized by parallel drainage systems of 1^{st}- to 3^{rd}-order with steep hydraulic gradients. The high ebb flow velocities in these steep drainage systems might prevent their overall retrogression.

Landscape perspective. The South Bay Ecosystem consists of four major landscape types that are distinguished by the composition, relative amounts, and natural arrangement of major habitat components (Collins et al. 2004). These distinguishing metrics relate to differences in freshwater influence and basin morphometry. Each type of landscape consists of a characteristic habitat mosaic, usually in association with a dominant habitat type.

Freshwater Landscapes are characterized by perennial fluvial drainages and emergent groundwater that create broad salinity gradients extending into the intertidal zone. The fluvial channels form deltas or fans bordered by brackish tidal marsh. Fluvial levees attend the streams part way through the marshland. The fluvial channels transition into large tidal sloughs that bisect the intertidal zone and extend into shallow bay or deep bay. There are no sausals, but riparian forests of sycamore, willow, cottonwood, alder, and live oak border the fluvial channels downstream of the head of tide. Broad transitions between tidal marsh and wet meadow or seasonal wetland border the riparian zones. There are no salinas, but very large marsh pannes and some marsh ponds exist within the brackish tidal marshland. With increasing distance bayward, the density of tidal channel networks increases, the marsh pannes decrease in size but increase in number, and there are gradual increases in the relative abundance of saline marsh vegetation along the channels and on the marsh plain.

In the West Side and Southeast Saline Landscapes, freshwater influences are restricted to uplands adjacent to the intertidal zone. The adjacent fluvial channels dissipate into distinct alluvial fans that slope downward toward the backshore. Seasonal wetlands, including vernal pools in some locales, attend the lateral margins of the fans. Very large sausals exist between the middle reaches of the fans and the backshore. The tidal marsh plain contains numerous small pannes, some marsh ponds, and is densely innervated by complex dendritic channel networks. Salinas extend prominently along the backshore. In the West Side Saline Landscapes, the 5^{th}- and 6^{th}-order channels tend to be much wider and they extend across the tidal flats into shallow bay. The narrower large channels in the Southeast Saline Landscape do not extent across the tidal flats.

The Salt Pond Lansdcapes lack sausals, distinct alluvial fans, nearby perennial or ephemeral fluvial channels, and there are few pannes in the tidal marsh. These landscapes are characterized by large salt ponds that replace tidal marsh and border extensive, un-channelized tidal flats.

Anthropogenic influences on ecosystem and habitat form and function. Ecological studies of estuarine habitats have focused as much on the values of diked baylands as tidal marshland (e.g., Anderson 1970, Jones and Stokes et al. 1970, Madrone Associates et al. 1983, BCDC 1982, USFWS 1987, The Bay Institute 1987, LSA 1989). The emphasis on tidal marsh impacts increased after the listing of tidal marsh wildlife as endangered (USFWS 1984, Josselyn 1983, Josselyn and Bucholz 1984, Harvey et al. 1992, Dedrick 1989). The first detailed regional comparison of historical and modern wildlife habitats was conducted a decade later (Goals Project 1999). This latter study provided definitions of the major habitat types and quantified changes in their distribution and abundance. The amounts of shallow and deep subtidal areas in South Bay have not changed significantly since Euroamerican contact, although the shallow bay is apparently deepening (Foxgrover et al, 2004). The amount of tidal flat has decreased by about 12%. The amount of tidal marsh has decreased by about 88%, and the amount of salt pond has increased by more than 1000%.

The shape and size frequency of tidal marshes have also significantly changed. A recent study of the fragmentation of South Bay tidal marsh for Clapper Rails (Collins et al. 2004) reveals significant decreases in the number of large patches, increases in the number of very small patches, increases in the complexity of patch shape, and increases in the minimum inter-patch distance and spatial isolation of medium-sized and large patches. These changes correlate to percent development of adjacent uplands and amount of diking, which in turn correlate to human population density. Very little historical marsh remains. Almost all of the existing marsh consists of long meandering patches that have formed along the remnants of historical 5^{th}- and 6^{th}-order channels between the reclaimed marshlands.

The large tidal channels that historically reached shallow or deep bay, or at least crossed the tidal flats, now dissipate near the middle of the intertidal zone. The large-scale reclamation of tidal marshland has therefore reduced the connection between the intertidal zone and the subtidal environments. One consequence is an increased need to dredge the channels to meet objectives for navigation and flood control.

Early agricultural development of the uplands in South Bay included extensive ditching to drain the valley bottoms and alluvial fans (Grossinger and Askevold 2004). This has greatly increased the number of hydrological connections between the uplands and the intertidal zone. These new connections, plus increased discharge from the urbanized landscape, plus the insertions of stormdrains and discharges from POTWs has redistributed in time and space the influence of freshwater.

Regional and local agriculture and urbanization has lead to the damming of major streams in the South Bay Ecosystem. Damming and grazing in the upper watersheds tend to increase channel incision and bank erosion (Dunne and Leopold 1978 and many others). Urbanization has also resulted in the construction of more than 30,000 roadways across fluvial channels. Many of these crossings are engineered to convey flood flows but not sediment bedloads. The bedload from upstream erosion therefore tends to accumulate behind the crossings (e.g. Collins 2001). Although upland development has increased the hydrological connection between the watersheds and the intertidal zone, it has inhibited the transport of bedload. Whether the damming of streams in their upper reaches and their downstream aggradation has altered the delivery of suspended sediment to the intertidal zone is not known.

The historical Saline and Freshwater Landscapes were significantly influenced by the availability of groundwater. Draining of artesian flows in Santa Clara Valley and later consumption of groundwater by agriculture caused a significant depression of the water table near the historical marshlands. Wetlands and springs near the historical backshore were desiccated (Grossinger and Askevold 2004). By 1965, the water table that had been at or above the ground surface in the mid 1800s was depressed to 25 ft below ground level (Santa Clara Valley Water District). Groundwater extraction also caused as much as 13 ft of land subsidence near the historical marshlands (Santa Clara Valley Water District). Management of the water table since 1965 has allowed it to rise within a few feet of the subsided land surface. It is likely that groundwater will begin to re-emerge near the historical backshore within the timeframe of the Project.

In general, land use has decreased the amount of tidal marshland, increased its fragmentation, decreased the hydrological connection between the intertidal zone and subtidal environments, increased the number of hydrological connections between fluvial systems and the intertidal zone, and decreased the connection between the intertidal zone and adjacent groundwater. The landscape types have been vertically compressed by the loss of subtidal connection to the intertidal zone and by the conversion of upland transition zones to urban land uses. Size has decreased for Saline and Freshwater Landscapes and their habitat components, but has increased for the Salt Pond Landscapes. The number of Freshwater Landscapes has increased due to the number of ditches and other unnatural connections between the intertidal zone and fluvial drainages. Reclamation has shortened the high tide boundary of South Bay from about 7,200 km to about 1,800 km (Collins et al. 2004). For many functions that are ascribed to marsh margins, such as water filtration, nutrient exchange, fisheries and passerine bird support, and plant biological diversity, this loss of edge represents a substantial reduction in ecosystem function.

What is the level of certainty of our knowledge?

The understanding of historical states and natural formative processes of landscapes, habitats, and habitat elements probably exceeds the understanding of existing states. This is because effects of people on the formative processes are difficult to quantify apart from natural change. The analytical data typically lack evidence of interim conditions between the distant and very recent past. Key thresholds of landscape or habitat response to land use or management actions are also not known. For example, while the elevation threshold for intertidal plant colonization is fairly well understood, the threshold of elevation or cover density that corresponds to significant decreases in inorganic sediment demand is not known. Therefore, tidal marsh restoration cannot be scaled to match the availability of suspended sediment. The threshold of marsh patch size for sustaining tidal channel networks might be known, but the influence of freshwater inputs or various edaphic factors such as grain size on channel formation is not known. The habitat affinities and food preferences are well known for key wildlife species, but their minimum viable habitat patch sizes and optimal spatial array of patches are not known. The ability of tidal marsh vegetation to respond to changes in hydroperiod is well known, but the limits of response are not known. It is also unknown, therefore, how interactions between vegetation growth, inorganic sediment supply, and hydroperiod will enable or prevent responses of restored marshland to increased rates of sea level rise. Long term success of the Project may depend on a sustained supply of sediment from local watersheds. Sediment yield from local watersheds can be measured, but the threshold response of the watershed to sediment management is not known. Furthermore, the Project is likely to be phased, and one phase may affect another. For example, early phases may alter sediment supplies for later phases, and these effects may vary depending on the relative positions and sizes of the phased efforts. Simply stated, the ecological services of the landscapes and habitat types are well enough understood to draft broad restoration guidelines, but scaling and phasing of the restoration efforts probably cannot be prescribed at this time.

What predictive tools exist for gaining an understanding of these issues and what tools are needed to reduce uncertainty to an acceptable level?

The proposed approach to predict the effects of ecological restoration relies on hydro-geomorphic models to estimate the rate of habitat development, and models of wildlife movement and survival to predict ecological endpoints, such as species composition and population density. The uncertainty of near-term geomorphic outcomes for any given set of starting conditions can be improved by further empirical studies of the demand of intertidal habitats for suspended inorganic sediment, how this demand varies in time as habitats evolve, and how supplies compare to demand. The uncertainty of geomorphic outcomes grows as the forecasts extend into the future because changes in the climatic, geologic, and land use processes that ultimately control sediment and water supplies cannot be exactly known. Even with the best possible models of habitat response to changes in water supply and sediment supply, conditions at the 50-yr Project horizon probably cannot be known well enough to map. There are no sources of data to calibrate models for the response of habitats to climatic changes that are unprecedented in the record of habitat evolution in this region.

Adaptive management of phased implementation of broad restoration guidelines may be the best tool for dealing with the near-term uncertainty that can be resolved with more data and the long-term uncertainty due to changes in habitat controls that cannot be exactly known. Each phase of restoration might be designed to answer questions about formative processes and ecological responses that reduce the uncertainty of subsequent phases. This adaptive approach is likely to extend the life of the Project to accommodate research and adjust the guidelines. One advantage to this adaptive approach is that it eliminates the need for a Project horizon. The 50-yr horizon that has been adopted by the Project bears no relation to any known periodicity or rate of natural processes or known administrative cycles except the planning period for projects funded through the federal Water Resources Development Act (WRDA). Another advantage is that it affords the Project time to adjust to unforeseeable changes in habitat controls, restoration constraints, or opportunities. A related advantage is that the phased adaptive approach could enable better integration of the Project with local watershed management initiatives, such that the Project has a greater chance to influence the upland supplies of water and sediment, and to improve the overall health of the South Bay Ecosystem.

What are the potential restoration targets and performance standards for evaluating the progress of the restoration project?

An analysis of the historical form and structure of South Bay landscapes, habitat mosaics, and their component habitats may provide a basis for developing landscape and habitat targets for the Project. The habitat mosaics reflect natural associations and arrangements of habitats for landscape types that reflect basic hydrological gradients and topography that either still exist in South Bay or can be recreated. The existing salt pond complexes at Eden Landing, Ravenswood, and Guadalupe River have the basic physiographic structure of the historical Salt Pond, West Side Saline, and Freshwater Landscapes. The restoration designs for these complexes might emphasize their historical habitat mosaics. It should be noted that there is no a-priori minimum patch size for salinas, marsh pannes, salt ponds, or sausals. Mosaics of small patches of these habitat types might be restored in smaller landscapes than existed historically. The existing salt pond complexes are large enough to accommodate large salt ponds in the context of replicate 4^{th}- and 5^{th}-order tidal marsh drainage systems, with their full complement of channels large and small, marsh pannes, and marsh ponds.

The early salt works of South Bay might serve as a model for restoration and maintenance of salt ponds. The salt works of the early 1900s featured salt ponds of a few to many hectares that were essentially elaborations of natural salinas and marsh pannes. The salt ponds were therefore naturalistic in shape, and high marsh plains without channels surrounded the salt ponds, protecting them from erosion and sediment input. Levees were low and easily repaired. Windmills were used to move water to and from ponds. The moderate size of the salt ponds afforded easy control of water levels and salinity with minimum energy expenditures.

The historical distribution of tidal flats and marshland might serve to guide the overall future distribution of restored tidal habitats in South Bay. For example, the size-frequency distribution of historical and restored patches might be compared, as could their patterns of isolation and association. The simple measures of total high tide edge and low tide edge might be the most robust indicators of habitat change at the landscape scale. Any tidal marsh restoration would increase the lengths of edge, but the restoration of marsh with dendritic channel networks, pannes, and ponds would increase the edge more. Erosion or submergence of tidal flat or marsh would reduce the length of edge. A similar measure could be used to track changes in salt pond and other lentic habitats. In this case, the edge of the ponded area would be measured. Ponds with naturalistic shapes would provide more edge than unnatural ponds. It is expected than many ecological objectives of the Project, including support of shorebirds, special status species, and fisheries relate to the amount of tidal edge created by the Project.

What key questions essential to the success of the restoration need to be addressed through further studies, monitoring, or research?

The South Bay Ecosystem should encompass the sources of sediment and water that control the evolution and natural maintenance of the key habitat types. To determine if the South Bay Ecosystem as delimited here meets this criterion, the historical amounts of shoreline progression and retrogression within the Ecosystem might be measured. If no forces within the Ecosystem drive a net loss or gain in shoreline position, and if the advances and retreats by the shoreline are approximately compensatory, then it might be concluded that the shoreline is controlled by changes in sediment and water supplies internal to the Ecosystem.

Project success may depend on phasing restoration to match sediment demand to sediment supply. This approach requires quantifying how the demand for inorganic sediment changes with marsh age and across the developing marsh plain. This could be ascertained by coring through well-developed marshes at varying distances from channels and tidal sources within the selected marshland, developing chronologies for the cores, and subsequently quantifying the changes in amount of inorganic sediment through time. The result would be a three-dimensional map of inorganic sediment demand per tidal marsh drainage system. Once the sediment demand is understood, then potential South Bay supplies can be assessed.

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Issue 2. Sediment management: Creating desired habitat while preserving existing habitat

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This synthesis summary is neither a complete literature review nor a conceptual model. The purpose of the synthesis is to answer six questions regarding the sediment management issue and restoration of the South Bay salt ponds. The Project Team is developing a conceptual model of sediment transport in South Bay. A draft synthesis has been completed.

What is the importance of the issue as it relates to the Project Objectives?
Project objective 1 is to create, restore, or enhance habitats of sufficient size, function, and appropriate structure to promote restoration and support increased abundance and diversity of native species in South San Francisco Bay. In order to create these habitats, the Project must convert existing nontidal submerged salt ponds. The levees around the ponds will be breached to connect the ponds to the estuary and allow tides to vary the water level in the ponds. Most of the ponds are below intertidal marsh elevation (Siegel and Bachand 2000). Thus, the elevation of the ponds must be increased to develop an intertidal marsh. Once established, vegetation helps the marsh develop by trapping additional sediment and providing

organic material. As land subsides and sea level rises, sedimentation is needed to maintain the elevation of the marsh relative to sea level. The rate of sedimentation will determine whether and when the project objectives will be met.

Natural sedimentation is dependent upon:

- Sediment supply from local tributaries and Bay waters.
- Transport of sediment from the Bay and sloughs into the pond by tidal currents.
- Deposition and retention of sediment in the pond.

Restoration actions have the potential to destroy valuable habitat. One effect of breaching a pond to a tidal slough or Bay is to increase the tidal prism of South Bay and the slough. If the tidal prism increases, tidal velocities must increase. Increased velocity can cause erosion in the slough and in the Bay (Shellenbarger et al. in review). This erosion may cause loss of existing marsh or tidal flats. An example that is similar to salt pond restoration is marshes in the Medway Estuary that had been enclosed by levees beginning about 1700 and were breached by tides in the 1880s. Recently, the marshes have been accreting while the salt marsh creeks and cliffs and tidal flats have eroded (Kirby 1990).

Another effect of restoration will be to alter the sediment budget of South Bay. Some of the sediment supplied by South Bay tributaries will deposit in breached ponds. To compensate for the loss of sediment to the breached ponds, erosion must increase or the amount of sediment leaving South Bay must decrease. The relative change in erosion and sediment export will determine the extent of habitat loss. Thus, the future sediment budget of South Bay is a key issue that will determine how well the project meets its objectives.

The primary concern with sediment is the creation and loss of desired habitat, but sediment affects flood control, public access, and water and sediment quality. This synthesis will focus on the creation and loss of desired habitat.

What do we know about this issue as it relates to the Project?
Several factors determine whether and how rapidly marsh habitat is created.

- *Pond elevations:* 61 percent of salt ponds have bottom elevations between mean tide level and mean higher water (Siegel and Bachand 2002). 22 percent of the ponds, all within the Alviso system where subsidence has been greatest, are below mean tide. As of summer 2004 USGS is collecting more detailed data for numerical modeling (Takekawa et al. 2003). Subsidence, uplift (Ferritti et al. 2004), and sea-level rise (Flick et al. 2003) change pond elevations relative to sea level.
- *Sediment supply from tributaries:* The USGS measures sediment load on the Guadalupe River, Alameda Creek, and Coyote Creek (Smithson et al. 2004). Sediment sources, transport pathways, and loads of streams tributary to San Francisco Bay are reviewed by McKee et al. (2003).
- *Sediment supply to ponds from Bay:* USGS has continuously monitored suspended-sediment concentrations in the deep channel of South Bay for over a decade (Buchanan and Ganju 2004). South Bay is most turbid in spring and early summer when a strong seabreeze generates wind waves and resuspends bottom sediment on the shoals (Schoellhamer 1996). The annual maximum of suspended-sediment concentration in South Bay is typically during the spring tide following the end of the spring phytoplankton bloom (Ruhl and Schoellhamer 2001).

- *Sediment loss to the Ocean:* The wind also generates a return flow moving toward the ocean in the deeper parts of the main channel (Walters et al. 1985). This is believed to be the pathway by which sediment leaves South Bay during summer. Some of the sediment delivered by large tributary inflow during winter flows out of South Bay. A sediment budget for water years 1995-2002 based on a simple numerical model calibrated to bathymetric change data (Foxgrover et al. 2004) indicates that sediment is exported from South Bay to Central Bay at a rate of 1.2 million metric tons per year (Shellenbarger et al. 2004).
- *Transport of sediment to ponds:* Suspended-sediment concentration on the shoals is greater than in the deep channel (Schoellhamer 1996). This turbid water enters the deep channel during ebb tides. During flood tides, it is likely that this turbid water enters the sloughs adjacent to the ponds.
- *Deposition at restored sites in South Bay:* Rapid deposition at the Warm Springs (also called Coyote Creek Lagoon) restoration site in Fremont filled the 4 m deep borrow pit to intertidal mudflat within 10 years (Williams 2001, Faber 2003). Wind waves can resuspend sediment that had deposited in a pond and reduce the net deposition rate (Williams and Orr 2002).
- *Vegetation colonization at restored sites in South Bay: Spartina foliosa* is typically the first vegetation to colonize depositing mudflats in San Francisco Bay. The mud flat elevation should be 0.2 to 0.4 m above mean tide for colonization. Once colonized, vegetation can expand to lower elevations (Williams and Orr 2002).

Project-induced erosion of existing habitat will be determined by changes in sediment supply and tidal prism. As impounded lands are opened to connect with the estuary, there will be an increase in tidal prism, water velocities, and erosion potential. Channels under the pressure of an increased tidal prism will first downcut (i.e., get deeper), thus increasing the steepness of the channel banks and leading to subsequent bank slumping and channel widening (Williams 2001; Orr et al. 2003). The relative increase in tidal prism and thus the likelihood of habitat loss decreases with distance from the project (Federal Aviation Administration 2003).

Seaward of the slough channels are the tidal flats of South Bay. South Bay currently has 58 km^2 of tidal flats, down from 92 km^2 in the 1850s (Foxgrover et al. 2004). This constitutes over half of the existing tidal flat area in the bay (Goals Project 1999).

What is the level of certainty of our knowledge?

The certainty of our knowledge of the factors that determine whether and how rapidly marsh habitat is created is:

- *Pond elevations:* Pond elevations will be well known upon completion of USGS surveys. Present rates of sea level rise and subsidence are well known.
- *Sediment supply from tributaries:* The USGS presently measures sediment load in the 3 largest tributaries above the extent of tidal influence. Changes in sediment load downstream from the gauges and sediment load from minor tributaries are not measured and are uncertain. Sediment load measurements on South Bay tributaries began in 1957, stopped by 1973, and began to be resumed in 2000. During the 30 to 40 year hiatus, the South Bay watershed became much more urbanized, so the historical records may not reflect present conditions.

- *Sediment supply to ponds from Bay:* Certainty decreases as one moves from the deep channel into the shoals and into the sloughs because monitoring programs have historically focused on the deep channel.
- *Sediment loss to the Ocean:* Although the southern part of South Bay was depositional and the northern part erosional, we are certain that there was net export of sediment from South Bay 1956-1983, and we do not expect that this trend will change 1983-2004. The available sediment export rate estimate is akin to a fancy back of the envelope calculation so the certainty is less. There has been no direct measurement of sediment transport at the seaward boundary of South Bay.
- *Transport of sediment to ponds:* There has been no direct measurement or quantification of sediment transport from the Bay to the sloughs or restored sites.
- *Deposition at restored sites in South Bay:* Data from restored sites can and has been used to determine overall deposition rates, but these rates are probably site specific for specific hydrologic conditions not likely to be repeated.
- *Vegetation colonization at restored sites in South Bay:* The basic process of vegetation colonization is known. The qualitative effect of vegetation on sedimentation is known but quantification is less certain. Invasive species introduce additional uncertainty.

Whether and how much existing habitat will erode is uncertain. Changes in tidal prism can be estimated with certainty, but geomorphic changes in response to tidal prism changes are uncertain. Besides tidal prism, sediment supply affects habitat erosion and is uncertain.

What predictive tools exist for gaining an understanding of this issue and what tools are needed to reduce uncertainty to an acceptable level?
The tools available for predicting sediment transport and geomorphic response to restoration actions are much less accurate than hydrodynamic or hydrologic models. While numerical modeling will be very important for comparing the relative outcomes for different restoration scenarios, we expect that the uncertainty in predictions of how long establishment of tidal marsh will take or how much erosion of mudflats will take place will not be small enough to ensure that the selected scenario will attain the goals of the Project. For this reason the Project must be designed to respond to adaptive management. For adaptive management to succeed, the Project needs to focus efforts on determining the best ways to monitor whether the project is proceeding as predicted, including detecting changes in bathymetry and sediment cycling, determining what levels of change in these parameters is acceptable, and distinguishing between change caused by the project and other sources of change.

Specific suggestions for predictive tools are given below and application of multiple approaches is often the best way to reduce uncertainty.

- *Sediment supply from tributaries:* Continued or expanded measurement of sediment supply from tributaries and adding or transferring measurements into the tidal reaches of channels closer to the ponds would improve our database and thus predictive capability.
- *Sediment supply to ponds from Bay:* Numerical models, similar to those developed for other restoration projects in San Francisco Bay (e.g. Bair Island, Napa/Sonoma marsh) are used to predict sediment supply. Field data are needed to calibrate and validate the models to reduce uncertainty.
- *Sediment loss to the Ocean:* Multidimensional numerical models are the best predictive tool available. Field data are needed to calibrate and validate the models to reduce uncertainty.

- *Transport of sediment to ponds:* Multidimensional numerical models are the best predictive tool available. Field data are needed to calibrate and validate the models to reduce uncertainty. Such measurements greatly improved our understanding of the Napa/Sonoma marsh sloughs (Warner et al. 2003) and provided data for developing models used to design the restoration.
- *Deposition at restored sites in South Bay:* Numerical models are the best predictive tool available. Zero-dimensional models that calculate deposition from an average sediment concentration have reasonably predicted deposition at restoration sites (Krone and Hu 2001). Field data are needed to calibrate and validate the models to reduce uncertainty.
- *Vegetation colonization at restored sites in South Bay:* The empirical observations that have been developed for San Francisco Bay can be used to predict future vegetation colonization. The behavior of invasive species is uncertain and perhaps not predictable.

Geomorphic evolution, in response to tidal prism change, may be predicted with empirical relations and numerical models. Detailed surveying of breaches, adjacent sloughs and mudflats, and elevated marsh would improve empirical relations, if done with appropriate spatial and temporal density. Monitoring of geomorphic responses to breaches would also provide data for development and testing of numerical models. Decadal geomorphic simulations in estuaries are not as well-developed as hydrodynamic simulations at the tidal timescale.

What are potential restoration targets and performance measures, linked to the Objectives, for evaluating the progress of the restoration project and what management measures might be used to reduce negative impacts?

The Project Team is experienced in designing restoration projects and they would probably have additional valuable suggestions.

Performance measures:

- Deposition rates and volumes in breached ponds
- Breached pond elevations
- Vegetation colonization in breached ponds
- Erosion of slough channels
- Change in existing marsh area
- Change in mudflat area, elevation, and volume
- Ecosystem function of ponds, breached ponds, sloughs, and mudflats

Possible management measures to reduce negative impacts:

- Dredged materials placement to accelerate restoration and reduce new tidal prism
- Time breaches (seasonal, tidal) for maximum initial deposition
- Phased breaches to increase tidal prism slowly
- Locate breaches to minimize damage to sloughs most susceptible to erosion from increased tidal prism
- Limit additional tidal prism by keeping ponds isolated or developing muted tidal ponds
- Temporary or permanent barriers to control which channels have increased tidal prism
- Connect adjacent sloughs to create a zone of flow convergence and sediment deposition
- Monitor slough and mudflat erosion and alter breaches if necessary

What key questions essential to the success of the restoration need to be addressed through further studies, monitoring, or research?

- How much sediment is needed for each restoration alternative?
- What will the rate of sediment supply to the restored ponds be?
- How will South San Francisco Bay evolve as tides are restored to the salt ponds?

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Issue 5: Managing Salt Ponds to Protect Migratory Bird Diversity and Abundance

A. Importance of the issue as it relates to the Project Objectives?

(from Warnock et al. 2002)

San Francisco Bay contains the most important salt pond complexes for waterbirds in the United States, supporting more than a million waterbirds through the year (Accurso 1992; Page *et al.* 1999; Takekawa *et al.* 2001). Single day counts of waterbirds in the salt ponds during winter months can exceed 200,000 individuals (Harvey *et al.* 1992), and single day counts during peak spring migration have exceeded 200,000 shorebirds in a single salt evaporation pond (Stenzel and Page 1988). The Bay and its surrounding salt ponds are significant habitat for waterbirds including Canvasback (*Aythya valisineria*) (Takekawa and Marn 2000), Ruddy Duck (*Oxyura jamaicensis*) (Miles 2000) and a number of shorebird species (Stenzel and Page 1988). Approximately 10% of the federally threatened U.S. Snowy Plover (*Charadrius alexandrinus*) Pacific Coast population breeds at San Francisco Bay, mainly in the South Bay salt ponds (Page *et al.* 1991).

At issue here, is the potential effect of the restoration of the 15,000 acres of South Bay salt ponds recently acquired by state and federal agencies to other habitat types, particularly tidal marsh habitat. Despite the documented importance of San Francisco Bay salt ponds to populations of Pacific Flyway waterbirds, few guidelines exist for state and federal wildlife agencies on how to actively manage a significantly smaller amount of salt pond habitat in the South Bay than currently exists to achieve the maximum abundance and diversity of birds using the habitat while keeping maintenance costs and efforts to a minimum. Additionally, little is known on how bird populations will change on the local, regional, and global scales as the salt pond restoration progresses.

B. What do we know about this issue as it relates to the Project?

Commercial salt ponds in San Francisco Bay have existed for over a century (Ver Planck 1958). Prior to European settlement, perhaps 800 ha of natural salt crystallizing ponds were found primarily in southern reaches of the Bay. A series of these ponds of about 400 ha were farmed for salt by the native Yrgin tribe (Goals Project 1999). Beginning with European colonization around the mid 1800s, extensive diking of tidal wetlands occurred to create salt ponds (Josselyn 1983), with accelerated conversion of tidal marsh to salt ponds from the 1930s through the 1950s (Goals Project 1999). Presently, there are over 12,000 ha of salt ponds in San Francisco Bay (Goals Project 1999), most in the south region of the Bay.

Coastal salt ponds (solar ponds, or salinas), areas where salt is extracted from salt water through solar evaporation, provide important nesting, foraging, and roosting habitat to waterbirds world-wide (Rufino *et al.* 1984; Sampath and Krishnamurthy 1989; Velasquez 1993; Masero and Pérez-Hurtado 2001). For instance, in Australia, three of the ten most important areas for shorebirds encompass commercial salt ponds (Lane 1987), while in Puerto Rico, the Cabo Rojo salt complex holds more shorebirds than any other site on the island and is one of the most important shorebird areas in the Caribbean (Collazo *et al.* 1995). Along the Pacific coast of North America, salt pond habitat supports significant numbers of waterbirds as recorded at critical Pacific Coast sites such as Laguna Ojo de Liebre, Baja California del Sur, Mexico (Page *et al.* 1997); San Diego Bay, California (Terp 1998); and San Francisco Bay, California (Page *et al.* 1999).

Roosting Habitat (to be filled out)

- Species of birds roosting
- Numbers of birds roosting
- Fidelity to roost sites
- Alternative roost sites

Movements among roost sites
Physical Characteristics of roost sites
Landscape characteristics of roost sites
Information from other areas

Foraging Habitat (to be filled out)
Species of birds roosting
Numbers of birds foraging
Fidelity to foraging sites
Alternative foraging sites
Movements among foraging sites
Physical Characteristics of foraging sites
Landscape characteristics of foraging sites
Diet of birds
Dynamics of prey populations
Information from other areas

Breeding Habitat (to be filled out)
(From Rintoul et al. 2003)

Species of birds breeding – Rintoul et al. (2003) assessed the status of breeding populations of Black-necked Stilts (*Himantopus mexicanus*) and American Avocets (*Recurvirostra americana*) in South San Francisco Bay, California, in May 2001. We counted 1,184 stilts and 2,765 avocets. Considering only birds observed exhibiting breeding behaviors, our low estimates of breeding birds in the South Bay were 270 stilts and 880 avocets, but actual numbers are probably closer to the number of stilts and avocets we actually counted. Our breeding size estimates fall within the range of similar estimates from the South Bay from 20-30 years ago. We know of no other sites on the Pacific coast of the United States that have breeding populations of stilts and avocets that approach those of the South Bay in size. The greatest numbers of stilts and avocets bred on salt ponds in the South Bay with lesser numbers breeding in a combination of fresh and salt marshes. The observed use by stilts and avocets of available habitat differed significantly from expected use. Stilts used tidal marsh and salt pond habitat approximately in order of availability, whereas avocets made greater use of salt ponds. Within marshes, stilts most often used vegetated areas followed by mudflat/open water habitat, whereas for avocets the pattern was reversed. Within salt ponds, both species were most often observed on islands, but their order of use of other microhabitats in salt ponds differed. We observed little use of tidal flats by breeding stilts and avocets.

Numbers of birds breeding
Fidelity to breeding sites
Alternative breeding sites
Movements among breeding sites
Physical Characteristics of breeding sites
Landscape characteristics of breeding sites
Demography of breeding birds
Information from other areas

C. What is the level of certainty of our knowledge?
(to be filled out)

D. **What predictive tools exist for gaining an understanding of this issue and what tools are needed to reduce uncertainty to an acceptable level?**

These sections need expansion

a. PRBO Habitat conversion models (Stralberg et al. 2003)
b. Phil Williams Associates – They have developed sediment models although have not been carried over to biota such as effects on birds
c. USGS models - see North Bay literature (Takekawa et al. 200?, 200?)

E. **What are potential restoration targets and performance measures, linked to the Objectives, for evaluating the progress of the restoration project and what management measures might be used to reduce negative impacts?**

(to be filled out)

F. What key questions essential to the success of the restoration need to be addressed through further studies, monitoring, or research?

(From Warnock et al. 2003)

The management implications of this study are complex yet several recommendations stand out. For attracting maximum numbers and diversity of migrating and wintering gulls and shorebirds, ponds with exposed moist soil and shallow water up to about 10 cm deep are recommended. Deeper water ponds are needed for many of the ducks and divers. Salinities of ponds need to be maintained in several ranges, especially the range where fish can live (20-60 ppt), and in the range that promotes a high biomass of invertebrate prey important to a wide range of migrating and wintering shorebirds, waterfowl, gulls, and terns. Our results suggest this latter salinity range centers around 140 ppt. Roosting waterbirds used islands in the middle of salt ponds, and maintenance and creation of island habitat should be incorporated into management plans for salt ponds. An important yet untested component of maintaining salt pond habitat for wintering and migrating waterbirds will be to prevent ponds, especially the lower salinity ponds, from becoming vegetated since many species of waterbirds, especially shorebirds, use vegetated areas, such as tidal marshes, less than open habitat (Warnock and Takekawa 1995; PRBO unpubl. data).

As has already been pointed out for San Francisco Bay (Takekawa *et al.* 2001), in order to maintain current diversity and numbers of waterbird in San Francisco Bay, conversion to tidal marsh habitat will require a greater amount of habitat than the amount of salt ponds being converted. While it is known that the salt ponds of San Francisco Bay support a large number and diversity of birds, it is not known how these birds will react if salt pond habitat is reduced. This should be the focus of major research efforts.

(from Stralberg et al. 2003)

Research Needs

While the results of our preliminary analyses provide new quantitative and qualitative information about potential effects of tidal marsh restoration on South Bay bird communities, there are still many unanswered questions and data gaps that need to be filled.

Restoration Dynamics, Hydrology and Geomorphology

At the level of individual restoration sites, it would help to know more about what future restored marshes will look like, in terms of their hydrology and the resulting mix of vegetated marsh plain and open water habitat; whether they will resemble existing marshes; and how long they will take to establish. Issues like sediment availability (Haltiner et al. 1997, Williams 2001), contaminants (Hostettler et al. 1996), and invasive species (e.g., *Spartina alterniflora*) further complicate these questions (Ayres et al. 1999). The rate of marsh development and change in landscape mosaic over time will also be important in order to assess how bird populations will respond. Furthermore, the effects of new restoration on existing tidal mudflats—whether it will contribute to additional mudflat accretion or further reduce available sediments, causing a reduction in habitat—will be important for calculating the net impact on shorebirds, in particular.

Population Dynamics

Due to the previously described limitations associated with using habitat availability as a surrogate for bird population numbers, it will be necessary to assess the short- and long-term viability for populations of several species of interest, under various restoration scenarios. Population viability analyses (PVA) are one way to identify the limiting demographic parameters (e.g., reproductive success, recruitment and survival) for a population, and assess the population's probability of long-term survival under various scenarios (Boyce 1992, Nur and Sydeman 1999). For example, based on a PVA developed for the Pacific Coast population of the Western Snowy Plover (Nur et al. 2001), the population was shown to be sensitive to small changes in adult survival. In general, adult survival has been shown to be the most important limiting factor across shorebird taxa (Sandercock 2003). Reproductive success, however, is thought to be limiting for many species in that it fluctuates widely, compared to the relatively stable adult survival, and may be easier to influence through management (Nur et al. 2001).

Habitat Carrying Capacity

We also need to gain a better understanding of salt pond prey availability and carrying capacities for various species (Goss-Custard et al. 1996). The habitat conversion models assumed that all ponds were being used to their maximum potential. However, it may be that more individuals can be accommodated by fewer, high-quality ponds. Conversely, if habitats are already being used at carrying capacity, behavioral responses of birds and their prey to habitat reduction could create a decline in bird numbers even greater than in direct proportion to the area of habitat lost (Goss-Custard 2003).

Existing data on bird energetics and prey availability can be used to estimate a range of carrying capacities for each salt pond and other habitats. In Spain, using an energetic approach combined with an understanding of prey selection, Masero (2003) found that salt ponds (salinas) contributed 25% of the daily prey consumption of waterbirds in the winter and 79% during the pre-migration period compared with intertidal mudflats. Observational data can be used to help validate these estimates. Behavior-based models may also be useful.

Diet studies will be important to really understand what resources waterbirds are getting from salt ponds vs. tidal flats and tidal marshes. Some of this might be done through direct sampling (collecting birds – Anderson 1970, other refs) while other questions might be addressed through stable isotope analyses (refs).

It will also be important to look at seasonal variations in salt pond bird numbers, since the highest shorebird numbers appear to occur during spring migration (Davidson and Evans 1986, Warnock and Takekawa 1996, Takekawa et al. 2001), and salinity and depth conditions vary throughout the year based on rainfall and other weather elements.

Regional Habitat Availability

We need to learn more about regional habitat availability for the species that have been modeled, some of which rely predominantly on San Francisco Bay during the winter or as stopover habitat during migration. Species whose populations depend heavily upon San Francisco Bay, such as Western Sandpipers (Butler et al. 1996, Iverson et al. 1996, Bishop and Warnock 1998) and Canvasback (Accurso 1992) may be more strongly affected by changes in habitat availability if they are unable to adapt by using other coastal wetland areas instead. Models of west coast stopover and wintering habitat availability for several key species would help managers prioritize habitats for conservation and restoration, based on their regional importance (Warnock and Bishop 1996, Takekawa et al. 2002, Warnock et al. 2002). Spatial models can be combined with energetics information to characterize the suitability and relative value of migration stopover sites (Simons et al. 2000). Similar efforts with Pectoral Sandpipers in the Great Plains region indicated that more connected wetland landscapes may provide higher stopover value (Farmer and Parent 1997, Farmer and Wiens 1999).

Other Habitats

PRBO habitat conversion models distilled a diverse wetland landscape into two basic habitat types: salt ponds and tidal marsh. In reality, the South Bay contains many other valuable habitats, both natural and man-made. For birds, some other important habitat types include tidal mudflats (critical for shorebirds), seasonal wetlands, freshwater marshes, levees, and natural or constructed salt pannes. Future iterations of our model will attempt to include these habitats and the species that depend on them.

Optimization and Prioritization

An important next step for this effort is to develop an algorithm for selecting optimal configurations of tidal marshes and salt ponds that satisfy a given conservation objective. A key part of this exercise is to identify the appropriate currency, in terms of bird numbers and diversity. In addition, there is a need to derive spatially-explicit optimal solutions. Potential methods include mathematical optimization techniques (Nevo and Garcia 1996, Hof and Bevers 2002, Cabeza 2003) as well as numerical simulation models, such as the Spatially-Explicit Species Index (DeAngelis et al. 1998) and Spatially-Explicit Simulated Annealing (Ball 2000).

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Issue 7: Predicting Pollutant Effects on the Biological Functioning of the South Bay

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What is the importance of the issue as it relates to the Project Objectives?

Contaminants have the potential to hinder the success of the Project through four principal mechanisms:

1. increases in wetland habitat may **increase mercury accumulation** in the food web;
2. **legacy sediment contamination** may impact specific restoration sites;
3. restoration may cause a regional increase in South Bay contamination through **accelerating erosion** of buried Bay sediment; and
4. **new inputs** could degrade restored habitat.

Three of the Project Objectives could be adversely impacted by contaminants through these mechanisms. There is a significant potential for contaminants to impact Objectives 1A and 1C, which relate to creation, restoration, or enhancement of habitat for special status species and native species. These objectives could specifically be affected by increased mercury accumulation, legacy sediment contamination, or new inputs. Increased mercury accumulation is the greatest threat, as one of the key special status species benefiting from the Project, the California clapper rail, is particularly vulnerable to mercury and rail eggs in the region already have been found to contain enough mercury to cause embryo mortality. It is possible that increased mercury accumulation could jeopardize the success of the project with regard to restoring clapper rail populations. Objectives 1A and 1C may also be impeded by the impacts of legacy sediment contamination at specific sites, or new inputs of contaminants. Project Objective 4, "protect or improve water and sediment quality and take into account ecological risks caused by restoration," could be adversely impacted by each of the four mechanisms. Both local and regional impacts of the project on water and sediment quality are quite possible. Lastly, increased mercury accumulation or accelerating erosion could impact Project Objective 3 by increasing contamination of sport fish in the South Bay. This could increase human health risks associated with sport fish consumption, and prolong the existence of a fish consumption advisory for the region, contributing to limited public access to the Bay fishery.

What do we know about this issue as it relates to the Project?

Our understanding of contaminants in the region has increased greatly in the past decade thanks to several major efforts: the Bay Protection and Toxic Cleanup Program, the Regional Monitoring Program, the Mercury and PCB TMDLs, the CALFED Mercury Project, USGS studies, and US Fish and Wildlife Service studies. Enough knowledge has been gained from these efforts to allow the Project to address contaminant issues in an intelligent manner. However, many questions still remain, especially with regard to mercury, which is probably the water quality topic of greatest concern to the Project. An adaptive management approach, as prescribed by the Mercury Strategy developed by CALFED (Wiener et al. 2003), will allow the Project to continue to gain understanding and better manage water and sediment quality as it proceeds.

Enough information is available to support the plausibility of the four hypothesized mechanisms of contaminant impacts on the Project. The potential for increased mercury accumulation in the food web to occur and have a significant impact is well-established. Wetlands, especially newly created wetlands, can generally be expected to be sites of enhanced net production of methylmercury, the form which accumulates in the food web and poses risks to humans and wildlife (Davis et al. 2003, Wiener et al.

2003, Beutel and Abu-Saba 2004). Sulfur-reducing bacteria are abundant in wetlands due to the anaerobic conditions that prevail in these organic-rich environments, and these bacteria are the main methylators of mercury. Newly created wetlands have an even greater supply of organic material and exhibit even more net methylation. While the general expectation is for increased mercury accumulation in restored wetlands, it is likely that distinct spatial variation on multiple spatial scales exists in net methylmercury production in Bay-Delta tidal wetlands, including variation within each tidal wetland, among tidal wetlands in the same region, and among tidal wetlands in different regions. Understanding this spatial variation and its underlying causes will allow environmental managers to minimize the negative effects of mercury bioaccumulation as a result of restoration activities.

The potential impacts of mercury on the restoration of clapper rail populations is a serious concern. Recent research (Schwarzbach and Adelsbach 2003, Schwarzbach et al. 2004) indicates that mercury may be a significant mortality factor for Bay populations of the California clapper rail, due to a combination of its sensitivity and tendency to accumulate this toxic metal. The most recent sampling of rail eggs found concentrations thought to be high enough to cause embryo mortality (Schwarzbach and Adelsbach 2003). Other bird species in the region, especially terns, have also recently been found to accumulate potentially deleterious mercury concentrations. Other piscivores, such as harbor seals, are also highly exposed to mercury, though little is known about the potential impacts of this exposure.

Legacy sediment contamination is known to exist in the Bay and its watershed. Layers or patches of elevated concentrations of mercury in sediment are distributed throughout the Bay and its watershed due to past activities, especially mercury mining in the Guadalupe River watershed and hydraulic gold mining in the Sierra Nevada. Runoff from the New Almaden mercury mining district had a particularly large influence on sediment quality in the South Bay region. Salt ponds that were leveed off in the earlier 1900s when New Almaden was active were left with higher overall mercury concentrations. Mercury from urban runoff and industrial activities also has contributed to the presence of mercury hotspots around the margin of the Bay. The Bay Protection and Toxic Cleanup Program, the RMP, and other studies have also documented the presence of hotspots of PCBs, legacy pesticides, and other contaminants around in wetlands and other Bay margin habitats.

Accelerated erosion of buried Bay sediment is a potentially serious regional threat to South Bay water and sediment quality. Studies by USGS have shown that the South Bay and other parts of the Bay are undergoing net erosion (Jaffe et al xx), largely due to a reduced supply of sediment coming in from the Central Valley (McKee et al. xx). The Estuary is currently experiencing a sediment deficit (Williams 2003). This poses a significant problem with respect to recovery of the Bay from mercury and PCB contamination because the layers of sediment that are being uncovered were originally laid down in earlier decades when the Bay was generally more contaminated. Opening salt ponds to tidal action will create a new demand for sediment and increase the rate of erosion of buried sediment.

New inputs of contaminants from the watershed are a continuing concern. New inputs could enter restored habitat from either adjoining watersheds or the atmosphere. New inputs of a wide variety of contaminants from the watershed are possible, including legacy contaminants like mercury and PCBs, but also emerging contaminants such as PBDEs, pyrethroid insecticides, and others. These chemicals could affect species of concern either directly or indirectly through impacts on prey species at lower trophic levels. Watershed inputs will pose a continuing concern over the life of the project. Recent research suggests that mercury derived from atmospheric deposition may make a disproportionately large contribution to mercury accumulation in the food web. A hypothesis currently under consideration is that the mercury entering the Bay-Delta from atmospheric deposition alone may be enough to cause the degree of mercury contamination in the food web, as has been observed in other ecosystems (Wiener et al. 2003).

What is the level of certainty of our knowledge?

While enough is known about the four principal mechanisms of contaminant impact on the Project to clearly warrant concern, considerable uncertainties remain. In the face of these uncertainties, an adaptive management approach, with careful monitoring of Project impacts, will be essential to reducing uncertainties and minimizing negative impacts as the Project proceeds. Major uncertainties include:

- many aspects of mercury cycling, including which restoration projects will cause increased methylmercury exposure;
- the present distribution of contaminants in the areas to be restored;
- recent trends in erosion and deposition in the South Bay and the potential influence of salt pond restoration
- the sensitivity of key species to contaminants, especially with respect to mercury, but also other contaminants such as PBDEs and emerging contaminants; and
- the combined effects of multiple contaminants on local and regional scales.

What predictive tools exist for gaining an understanding of this issue and what tools are needed to reduce uncertainty to an acceptable level?

In the past few years the first steps have been made to begin to develop a capacity to predict regional trends in contaminant concentrations in the South Bay for the next 50 to 100 years. Studies have also been performed or are planned that are beginning to delineate processes and patterns in the Estuary and its wetlands and provide the foundation for a predictive capacity. However, our present ability to predict the impacts of the Project on contaminant cycling in South Bay is weak due to a lack of information on contaminant cycling and distribution. Empirical monitoring and research guided by model development will be the way to continue to develop a predictive capacity and reduce uncertainty. Tools that are needed include:

- a conceptual understanding of mercury cycling in Bay wetlands that allows prediction of mercury accumulation in restored habitats, including different subhabitats within wetlands;
- a model and sediment budget that accurately describes sediment mixing and erosion in the South Bay; and
- a long term program of monitoring and research that assesses contaminants prior to, during, and after each restoration project.

What are potential restoration targets and performance measures, linked to the Objectives, for evaluating the progress of the restoration project?

Restoration targets are the standards, based on scientific data, for successfully achieving Project Objectives. As no parts of the Estuary will be entirely free of contaminants, the reference condition for contaminants may be sites with relatively low concentrations. A review should be performed to determine whether restoration targets can be established based on existing data. If not, the Project should perform additional sampling of relatively clean habitats. The Regional Water Quality Control Board may establish restoration targets based on other criteria.

Performance measures are parameters or metrics used to assess progress toward the restoration targets. Food web monitoring is an essential performance measure for adaptive management of restoration in the Estuary, as prescribed by CALFED's Mercury Strategy (Wiener et al. 2003). Fish monitoring is especially important for mercury. Other types of monitoring are important for determining the impacts of other contaminants. Performance measures would include:

- concentrations of mercury and other contaminants in the food web (fish, bird eggs, seals);
- general health assessments of key species and communities;
- toxicity testing would be a way of screening for potential effects of current use pesticides and emerging contaminants; and
- contaminant concentrations in water and sediment.

Management recommendations for addressing negative impacts will principally come out of the process of adaptive management and monitoring. Our understanding of mercury in the Estuary is too limited at present to predict which actions or habitats will be associated with increased methylmercury exposure. Recommendations that are clear at this stage are:

- avoid restoration in areas with problematic amounts of pre-existing sediment or food web contamination – detailed surveys should precede restoration projects;
- avoid restoration in areas with significant continuing inputs of contaminants from local watersheds;
- monitoring and research should be an ongoing part of SBSP restoration for the duration of the project; and
- SBSP monitoring should be closely coordinated with other contaminant work in the region being done by RMP, CALFED, and others

What key questions essential to the success of the restoration need to be addressed through further studies, monitoring, or research?

The key questions relate to whether the four hypothesized mechanisms of contaminant impact on the Project actually occur, and include:

- the effect of different types of restoration on contaminant exposure in sensitive species;
- the effect of restoration on the South Bay sediment budget and long term trends in South Bay contamination;
- the sensitivity of target species, such as clapper rails, to contaminants; and
- present levels of contamination in locations to be restored.

Issue 8: Impact of Invasive Species and other Nuisance Species

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What is the importance of this issue as it relates to the Project Objectives?

Invasive or nuisance species are typically nonindigenous (otherwise known as “exotic” or “alien”) species that are introduced into a ecosystem either purposefully (I.E. agriculture, recreation) or on accident (I.E. ballast water) and have a perceived negative impact on that ecosystem through alteration of ecosystem function and/or structure. Not all “nuisance” species are nonindigenous, and may include native species that in relation to human activity or ecosystem alteration have a perceived negative impact.

The San Francisco Bay estuary is thought of as the most highly invaded aquatic ecosystems in North America. As of 1995, there were over 212 introduced species in San Francisco Estuary: 69 percent of these are invertebrates, 15 percent are fish and other vertebrates, 12 percent are vascular plants and 4 percent are probsts. In addition, since 1970, a new invasive species has become established once every 24 weeks (Cohen and Carlton, 1995). With so many invasive species, complete ecosystem functions are controlled by nonindigenous species. For example, the primary mechanism controlling phytoplankton biomass during summer and fall in South San Francisco Bay is "grazing" (filter feeding) by the introduced Japanese clams *Venerupis* and *Musculista* and the Atlantic clam *Gemma* (Cohen and Carlton, 1995).

Invasive and nuisance species can impact the restoration process through food web alteration, the prevention of ecosystem function, destruction or degradation of physical structure associated with restoration activities, predation or exclusion of desired sensitive species, and by dominating the biomass of a restored site.

The purpose of this report is to discuss the role of invasive species and other nuisance species with respect to the objectives of the restoration including a discussion of how design and management measures can maintain or improve current levels of vector management, control predation on special status species and manage the spread of non-native invasive species (Objective 5).

Without adequate control and prevention measures, invasive and nuisance species could ultimately hamper or ruin restoration efforts through displacement of desired species and prevention of suitable ecosystem establishment, prevention of physical restoration processes, or loss of special status species post-restoration. Many invasive and nuisance species are adapted for rapid colonization of disturbed areas, can compete with or directly impact special status species, disrupt the natural food web, cause harm to humans, or have a structural impact on restoration structures. These characteristics make these species difficult to control in the restoration environment and make them likely to impact post-restoration ecosystems.

What do we know about this issue as it relates to the Project?

San Francisco Bay is one of the most studied estuaries in the world and a great deal of information exists on the taxa, populations, and role of invasive species within this ecosystem. Despite this wealth of knowledge, very few individual invasive species have been studied in depth as to their specific ecological impacts, impacts on restoration, or potential for control.

Cohen and Carlton's 1995 study, *Nonindigenous aquatic species in a United States estuary: A case study of biological invasions of the San Francisco Bay and Delta,* is probably the most definitive source for information on invasive species in the San Francisco estuary including detailed species accounts for more than 200 invasive species. In addition to species accounts, this study reaches the following major conclusions regarding the impact of invasive species on the ecosystems and ecology of the Estuary:

• The Estuary is a highly invaded ecosystem with over 212 known and recognized invasive species present.
• Many of the Estuary's food webs and energy transfer processes are dominated by invasive species.
• Structural changes to specific habitats within the Estuary may be caused by invasive species.
• Invasive species contribute to the demise of endangered marsh birds and mammals.

Historically, invasive species have been transported into San Francisco Bay by boat and train for a variety of reasons. In the late 1800's gold rush, and with the completion of the transcontinental railroad in 1869, many species were introduced into San Francisco Bay for food. In addition to the introduction of desired species, the transport of harvest species into the Bay accidentally brought other invasive species attached to the desired species, in sediments transported, or in water transported. The transport of coastal or estuarine water (as ballast) continues to be one of the most significant vectors for invasive species today. The transport of invasive species through ballast water, and other vectors for invasive species introductions are discussed below:

<u>Ballast water</u>
Cohen and Carlton (1995) estimate that hundreds of species are released into the San Francisco Bay each month via ballast water releases. Planktonic estuarine organisms from around the globe can be released through this mechanism (Carlton and Geller, 1993). Oceangoing vessels transport organisms through the uptake, transport, and subsequent discharge of water from ballast tanks. A great deal of information related to ballast water exchange and transport of invasive species is currently available, and a number of laws have been passed that attempt to deal with this problem including the 1996 National Invasive Species Act that created a national ballast management program. Cohen (1998) reports that ballast water is responsible for the introduction of the Asian clam (*Potamocorbula amurensis*), now the most abundant clam in the Estuary.

There are a number of mechanisms to control invasive species introductions from ballast water including ballast water exchange and treatment. Ballast water exchange is the simplest and most cost effective method for helping reduce the number of coastal or estuarine species transported in ballast water. The basic concept is to require that ships exchange port water (usually lower salinity water) with open ocean water before returning to port. Typically estuarine or coastal species won't survive in the open ocean, and open ocean species will be less likely to establish in coastal areas, so less species with potential to occupy coastal port waters are introduced. Ballast water treatment comes in many forms including mechanical (filtration and seperation), physical (sterilization by ultraviolet light, ozone, heat, electric current, or ultrasound) and chemical (biocides). Ships can treat ballast water using one method, or a combination, either in port or in the open ocean. While this method can be more effective than ballast water exchange, it is typically less cost effective (Buck, 2004)

In the San Francisco Bay, a combination of methods may produce the best results at limiting introductions of exotic species from ballast water. Cohen (1998) recommends the following actions for the reduction of invasive species introductions through ballast water:

- Sample and assess arriving ballast water
- Collect and analyze data on shipping activity and ballast discharges.
- Encourage ships to utilize appropriate ballast management measures.
- Prohibit the dumping of ballast sediments.
- Require ships to conduct open-ocean exchange of ballast water, or an equally effective alternative treatment, subject to safety concerns
- Encourage ships to assess the safety of exchange methods, to use the safest approach if there is uncertainty, and to make any needed retrofits.
- Support research into on-shore treatment, including approaches tailored to the Bay/Delta region.
- Monitor and participate in the assessment of voluntary federal ballast water guidelines.
- Assess the power of existing laws to prohibit or reduce the discharge of exotic species in ballast water, and use them.
- If existing law is not adequate for this task, pass laws that are.

The following mechanisms for invasive species introductions to the Bay are less well studied and are generally less of a problem than ballast water releases, but may still be important factors in the establishment of exotic species in the Bay.

<u>Bait worm shipments/Live bait</u>
Shipments of various bait worms and associated kelps and unknown organisms mixed in with bait worms including snails, bivalves, amphipods, isopods, etc. is another potential transport mechanism. Packing material consisting of an east coast seaweed, *Ascophyllum nodosum*, is also dumped in the bay and has been detected and eradicated at Coyote Point in south San Francisco Bay. Releases of “red shiner” or other bait fish into freshwater locations of the delta can have adverse impacts on native species.

<u>Herring-roe-on-kelp fishery</u>
Macrocystis pyrifera collected in southern California has been placed in the San Francisco Bay as a substrate for herring spawning. *M. pyrifera* has become established in the Bay, and organisms associated or imported with the kelp may also be able to establish in the Bay.

<u>Private party (aquaria, for food/sport)</u>
Private party releases include releases of fish/shellfish including the Chinese mitten crab and white bass for food/sport, the release of turtles, fish, snails, etc from home aquaria, or releases from private recreational vessels. In addition, the intentional release or escape of cats and non-native red foxes has led to the spread of these predators into sensitive wildlife areas.

<u>Restoration/Scientific Research</u>
One of the most ironic introductions that has lead to serious ecosystem alteration was the intention planting of Atlantic smooth cordgrass (*Spartina alterniflora*) in a Corps of Engineers Dredged Material Demonstration Project in south San Francisco Bay in the 1970's. This introduction to test restoration planting methods has lead to one of the most profound ecological change in the vegetative structure of tidal marshes.

Species that are the most significant threats to successful restoration
The following list presents invasive or nuisance species that have a high potential to undermine restoration efforts. Factors considered in this determination include the species’ colonization or spread rates, potential to harm or displace special status species, potential to disrupt the natural food web, ability

to cause structural ecosystem alterations, and in some cases, available information and potential for control.

Invasive species:
Plants:
- Atlantic salt-marsh cordgrass (*Spartina alterniflora*)
- Broadleaf peppergrass (perennial pepperweed) (*Lepidium latifolium*)

Invertebrates:
- Asian Clam (*Potamocorbula amurensis*)
- Australian-New Zealand boring isopod (*Sphaeroma quoyanum*)
- Chinese mitten crab (*Eriocheir sinensis*)
- European green crab (*Carcnius maenas*)
- Atlantic ribbed marsh mussel (*Arcuatula demissa*)

Mammals
- Norway rat (*Rattus norvegicus*)
- Red fox (*Vulpes vulpes*)
- Feral cat (*Felis felis*)

Nuisance species:
Birds
- California Gull (*Larus californicus*)
- Common raven (*Corvus corax*)
- American crow (*Corvus brachyrhynchos*)

Invertebrates
- Mosquitos (*Culex* sp., *Ochlerotalus* sp. *Aedes* sp.)

What is the level of certainty of our knowledge?
Invasive species have had a major impact on the ecology of the San Francisco Bay. Tidal mudflats and shallow water habitats are almost entirely composed of introduced species, and native species are rarely found in abundance. In many cases, community structure and function within the Estuary is dominated by invasives creating "introduced communities." Also, in many locations throughout the Estuary, introduced species account for the majority of species diversity. Invasive species have achieved these levels of ecosystem dominance through a number of mechanisms including competition and exclusion of native species, alteration of physical habitat structure, and through the modification of food web structure.

Our knowledge of most of these species relates to their impacts to native systems. A few examples[1] demonstrate the extent of our understanding about these species:

Atlantic salt-marsh cordgrass (*Spartina alterniflora*)
Spartina alterniflora was first introduced into the San Francisco Bay in the early 1900's either through ballast water or sediment used as packing material for east coast oysters. In the 1970's, *Spartina*

[1] More examples are detailed in the full paper.

alterniflora may have been planted purposefully into the San Francisco Bay for shoreline stabilization, “restoration,” or in wetland mitigation. Due to its higher seed production and germination rate, *Spartina alterniflora* establishes new colonies faster than the native cordgrass. Once established, it outcompetes the native *Spartina*, growing 6 to 7 times faster (Callaway and Josselyn 1992). In addition, *Spartina alterniflora* can cause the displacement of native fora, changes in sedimentation, decreases in benthic invertebrate and algae populations, disturbance to the upper marsh and the loss of foraging sites for shorebirds and other animals. Because *Spartina alterniflora* has larger and more rigid stems, greater stem density, and higher root densities than native *spartina* it may cause major structural changes in the Estuary.

As of 2002, *Spartina alterniflora* had spread to over 3000 acres in South San Francisco Bay, and may eventually spread to over half of the intertidal flats within a couple decades (USFWS, 2003). Collins (2002) reached the following conclusions regarding the impacts, potential spread, and geomorphologic alteration of the Bay:

- NIS (non-indiginous spartina, including *Spartina alterniflora* and hybrids) cordgrass is unlikely to invade more than the upper half of the saline tidal flats and will tend to invade smaller proportion of the tidal flats in Far South Bay than in South Bay or Central Bay.
- NIS cordgrass will probably not dominate the saline high marsh above MHW (Mean High Water)
- The invasion of existing mid- and high-elevation marsh channel by NIS cordgrass will tend to isolate the headward reaches of first order channels from the rest of their channel networks.
- NIS cordgrass can cause second and third-order tidal marsh channels to retrogress, thus shortening and simplifying intertidal channel networks and the shoreline of the Estuary as a whole.
- NIS cordgrass can obstruct tidal flow and fluvial discharge in the upper tidal reaches of luvial drainages.
- The upper tidal reaches of local streams can serve as refugia for non-hybrid *Spartina Alterniflora* and as sources of new recruits for continued invasion around San Francisco Bay

Collins (2002) also addresses studies needs that could help determine the geographic extent and ecological impacts of the invasion. Studies are needed to determine: 1) The minimum elevation of NIS cordgrass in the lower intertidal under varied salinity conditions. 2) How marsh evolution, from tidal flat through low marsh to high marsh, is altered when the low marsh is dominated by NIS cordgrass. 3) How native plants and animals will adapt to the NIS cordgrass.

A great deal of uncertainty exists in how NIS cordgrass will impact the restoration process. Increased sedimentation rates and reduced mudflat areas are known impacts, but consequences for restoration are less clear.

Current control methods for *Spartina alterniflora* (and hybrids) include hand-pulling and manual excavation, mechanical excavation and dredging, pruning, flaming buring and mowing, covering/blanketing, flooding and draining, and the application of herbicides. Details on each method including benefits and drawbacks can be found in the 2003 San Francisco Esturay Invasive Spartina Control Program Final Programmatic EIR (REF).

Perennial pepperweed (*Lepidium latifolium*)
Perennial pepperweed is a creeping rooted perennial adapted to sites that are at least seasonally moist in riparian and wetland areas and is ranked a "B" level plant pest by California Dept. Food and Agriculture. It can establish on disturbed, bare soils, and seems well adapted to salt affected soils (Young *et al.*, 1995). Perennial pepperweed can compete with pickleweed, reducing habitat for the salt marsh harvest mouse and may outcompete rare native marsh plants *Lilaeopsis masoni* and *Cordylanthus mollis mollis*.

Perennial pepperweed is found in the South Bay, primarily along sloughs, and is a dominant component of marshes adjacent to Coyote Creek. Opportunities for further spread include high elevation tidal marshes, fresh-brackish marshes, brackish marshes with poor tidal circulation, along natural and artificial levees and berms within marshes, and on sandy beaches (Grossinger, 1998)

CDFG has tested burning, discing, and herbicide treatments as control measures for peppergrass. No fully effective method has been developed to date.

Asian Clam (*Potamocorbula amurensis*)
Introduced around 1986, the Asian clam has quickly become the most abundant clam in the estuary. A highly efficient filter feeder, the Asian clam ingests bacteria and small zooplankton as well as phytoplankton and has severely depleted phytoplankton populations in northern part of Estuary, altering food web structure and food availability for species higher in the food chain. May reduce zooplankton populations making introductions of Asian zooplankton more likely (Cohen, 1998, Nichols *et al.*, 1990). Since the introduction of the Asian clam typical summer phytoplankton blooms have been absent from the South Bay, presumably due to the Asian clam's aggressive filtering that overwhelms phytoplankton net production.

Australian-New Zealand boring isopod (*Sphaeroma quoyanum*)
A burrowing, filter feeding isopod native to Australia/New Zealand that has been in the San Francisco Bay for over a century. Today the isopod is common and frequent throughout San Francisco Bay. It burrows into all soft substrates including clay, peat, mud, sandstone, styrofoam docks, etc, and bores half-centimeter diameter holes that can lead to shoreline erosion. Talley *et al.* (2001) estimate that *S. Quoyanum* infestation can lead to losses of greater than 100 cm of marsh edge per year.

Atlantic ribbed marsh mussel (*Arcuatula demissa*)
One of the most common bivalves in the San Francisco Bay, including in salt marshes of the South Bay where is lies with its posterior margin protruding above the mud (called "endobyssate"). California clapper rail often get toes or beaks caught in the open valves of the mussel and can drown with incoming tide, or starve to death. The clapper rail also eats *Arcuatula*.

Chinese mitten crab (*Eriocheir sinensis*)
The Chinese mitten crab, *Eriocheir sinensis*, is a recently introduced species to the San Francisco Bay, presumably introduced through deliberate release to form a fishery or through ballast water releases (Cohen and Carlton, 1997). A native to coastal rivers and estuaries of Korea and China along the Yellow Sea, the Chinese mitten crab is a catadromous species with planktonic larvae that breeds in water with a salinity of approximately 25 ppt (parts per thousand). In the San Francisco Estuary, upstream migration occurs year-round with a peak in spring months, downstream migration primarily occurs in August-January with a peak in September-October (Veldhuizen and Stanish, 1999).

The Chinese mitten crab was first collected in San Francisco Bay in 1992, and populations have expanded rapidly since, with over one million mitten crabs collected in 1998 at Bay-Delta water transfer facilities. As of 1999, distribution of the mitten crab extended north of the Delevan National Wildlife Refuge in the Sacramento river drainage, east of Roseville in the American River drainage, south in the San Joaquin River draingage near San Luis National Wildlife Refuge, and south in the California Aqueduct to near Kettleman City and Taft (Veldhuizen and Stanish, 1999).

Well distributed in South Bay, throughout most of the sloughs and tidal creeks. They spend most of their lives in rivers and then migrate into estuaries to reproduce. Mitten crab burrows can cause accelerated bank erosion and slumping. Burrows can extend up to a half meter deep in mud banks. Potential impacts to San Francisco Bay ecosystems identified by the Chinese mitten crab Control Committee (2002) include:

- Weakening of levees and/or banks from mitten crab burrows, leading to increased maintenance/repair requirements, slumping and/or failure of banks/levees. Burrowing and slumping have been observed in San Francisquito and Stevens Creek.
- Mitten crab feeding behavior could cause a decrease in vegetation in agricultural fields and/or natural habitats.
- Water diversion/industrial/restoration activities could be disrupted by crabs blocking or clogging systems.
- Recreational and commercial fishing could be negatively impacted through the blockage or clogging of nets and traps, bait stealing, or damage to gear or catch.
- Native populations, community structure, and local biodiversity could be negatively impacted through predation, competition for resources, habitat alteration, or food-web disturbance
- Bioaccumulation and biomagnification of contaminants, disease transfer, and parasite spread could pose a health risk for the public or wildlife species that consume the crab either directly or through consumption of animals that prey or associate with the crab.

Population control measures for the Chinese mitten crab are poorly studied, and may not be effective. Current management strategies should include a plan for the prevention of further spread, detection of new populations, monitoring of existing populations and impacts, reduction of negative impacts, and development of population control strategies. Research needs include:

- Identification of natural and human induced spread including ballast water, ocean currents, recreational and commercial boat equipment, human transport and releases, and dredging.
- Establishment of standardized detection (including larvae), sampling, and monitoring techniques.
- Studies on biology, life history, environmental tolerances, critical habitats and impacts of the mitten crab including impacts on ecology, levees and agriculture, species at risk from mitten crabs.
- Evaluation of impacts, current and potential, to recovery and restoration efforts.
- Develop methods for population control measures including values, risks, and options.
- Focused study on feasibility, value, and potential for a population control program at fish salvage, fish passage, and water diversion operations.

Red fox (*Vulpes vulpes*)
First observed in the San Francisco Bay National Wildlife Refuge in the South Bay in 1986, and have been expanding their range (not to be confused with the native but extremely rare or extinct sierra nevada red fox, *Vulpes vulpes necator*). They are regularly seen in the South Bay in all habitat types and dens have been located in levee banks and in salt marshes (Foerster and Takekawa, 1991). The red fox is known to prey on clapper rail eggs, young, and sometimes adults, least tern, snowy plover, Caspian tern, black-necked stilt, and avocet. It may also prey on the salt-marsh harvest mouse, salt marsh wandering shrew, and California black rail. Red fox have been trapped and killed since 1991 as part of the San Francisco Bay National Wildlife Refuge predator management plan.

Mosquitos
A number of different mosquito species reproduce in South Bay marshes and wetlands including:

- Summer salt-marsh mosquito, *Aedes dorsalis*; prefers temporarily flooded tidal marsh pannes, heavily vegetated ditches and brackish seasonal wetlands in the San Francisco Bay.
- Winter salt-marsh mosquito, *Aedes squamiger*; prefers coastal pickleweed, tidal and diked marshes, and other brackish or saline habitats.
- Washino's mosquito, *Aedes washinoi*; prefers shallow ground pools and upland fresh or semi-brackish pools in close proximity to salt marshes or riparian cooridors.
- Western encephalitis mosquito, *Culex tarsalis*; breeds in all types of freshwater habitats.
- Winter marsh mosquito, *Culiseta inornata*; can be found in a wide variety of habitats including everything from rainwater pools and salt marshes to manmade ditches or containers.

Not all species of mosquitos have the same potential to carry West Nile Virus (WNV), although all mosquito species have the ability to carry WNV. Goddard et al. (2002) determined that *Culex* species tend to be more adept at carrying WNV, and *Culex tarsalis* is one of the most efficient laboratory vectors of WNV tested in North America. In addition, *Culex tarsalis* has the highest probability of any mosquito tested in this 2002 study to amplify and maintain WNV in California (Goddard et al. 2002). *Culiseta inornata*, a widely distributed winter mosquito in California, also has a relatively high infection rate, and moderately high transmission rate for WNV. The only *Aedes* species tested in this study, *Aedes vexans*, had much lower transmission and infection rates for WNV that either *Culex tarsalis*, or *Culiseta inornata*.

Birds infected with WNV have been found in every county in California except San Benito County, and Del Norte County. San Mateo, Contra Costa, and Alameda Counties have reported testing birds with WNV in 2004, however, the only Bay Area county reporting mosquitos infected with WNV is Solano County (USGS, 2004).

What predictive tools exist for gaining an understanding of this issue and what tools are needed to reduce uncertainty to an acceptable level?

Often the occurrence of an invasion is not noticed until it is too late to take action to control the species. In many instances, the scientific investigation focuses on the effect of the invasion rather than how to control or remove the invasive species. This is often a requirement of the regulatory agencies in that a justification is required in order to implement the sometimes temporary, but destructive, environmental impacts and to fund the costly control methods. In addition, persistence, coordination, and long-term funding is usually required. In only a few causes such as the *Caulerpa* invasion in a few coastal lagoons of southern California (ref) and the recent invasion and control of *Spartina alterniflora* in Bolinas and Tomales Bay has rapid eradication followed initial observations of the invader.

The same is true for nuisance species with the exception that they have usually been present in the environment for a long period of time and it is usually a combination of human presence, urbanization, and proximity to suitable resources (including prey) that create conditions where these species can be detrimental to natural habitats and their occupants.

Controlling the effects of these invasive and nuisance species on the environment falls into two primary categories: institutional and scientific. Institutional controls relate to legislative action on non-indigenous species, regulatory controls on new introductions, and development and coordination of government agencies in control and eradication programs. Much has been written on institutional controls (US Congress, 1993). While certainly important and vital to reducing the impacts of these species, further discussion of these controls are not relevant to this report.

While scientific knowledge of invasive species often focuses solely on the after affects of the invasion, some predictive tools have been developed. These predictive tools include modeling population and distributional trend analysis and ecosystem models (both conceptual and mathematical) that portray long-term changes resulting from either establishment or eradication of the species. Good examples of such analyses have been completed on *Spartina alterniflora* (Matsumoto 2004, Collins 2002). Likewise, the effects of the invasion of the Asian clam on the food webs of San Francisco Bay have also been documented (Nichols 1990).

The application of modeling to invasive species needs to be more thoroughly developed in order to more effectively communicate the importance of control. Graphic representations of the spread of a species or the diminishment of another native species are useful outcomes of population models calibrated with observations made in the field. It may be possible to include such modeling efforts into restoration experiments to test how sites where active controls are implemented differ structurally and functionally from those areas where controls have not been instituted. In addition, detailed observations and ecosystem modeling for sites where controls are being instituted now should be completed.

What are the potential restoration targets and performance measures, linked to Objectives, for evaluating the progress of the restoration project?

In an ideal world, the complete eradication of invasive and the control of nuisance species from restored sites should be a primary performance standard for the restoration project. Unfortunately, 200 years of invasion of the San Francisco Bay estuary cannot be reversed quickly or economically. Therefore, the decisions as to restoration targets and performance measures must be species specific. Fundamental questions that must be answered for each of these species include:

$ Does the species cause significant adverse impact on the native, natural environment?
$ Will control and eradication result in a measurable improvement in the natural environment or can other mechanisms be used to ameliorate the impact of the species on the environment?
$ Are there control and eradication methods available, effective, cost-effective, and socially acceptable?
$ At what level must control be enacted–towards complete eradication, limitations on distribution, or sustained, but low populations
$ Are there institutional mechanisms available to assure long-term control?

A decision matrix should be developed that then focuses on the appropriate level of control for each species as well as an evaluation of alternative measures (other than control) that might be set for the restoration project.

What key questions essential to the success of the restoration need to be addressed through further studies, monitoring, or research?

Scientific study is warranted on a number of fronts:

- What are the rates of invasion of newly restored habitats by non-indigenous species?
- How does invasion by non-native species affect the ecological "assembly rules" of a newly restored habitat?
- Can artificial transplantation of native species to a restoration site be effective in altering the influence of the non-native species?
- Is there a "low-level" population size or distribution of an invasive species that can be sustained over time without adverse impact on the natural environment?
- Are there other mechanisms in a restoration design that can limit invasion, i.e. hydrologic controls, topographic conditions, and/or sediment composition?
- Are there biological controls that can be developed to effectively limit invasive species?
- What monitoring tools are available to effectively detect invasive species prior to their becoming a problem in the environment?

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Issue 9: Effects of Human-related Activities and Structures on the Restoration Project
Part 1. Understanding Public Access and Wildlife Compatibility
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What is the importance of the issue as it relates to the Project Objectives?

An important Objective of the project is to provide high-quality recreation and public access compatible with wildlife (Objective 3). This will include trails, overlooks, and other structures to facilitate access. The science synthesis for Part 1 of Issue 9 addresses our understanding of public access and recreation impacts on the ecological Project Objectives (1A, 1B, 1C). US Fish and Wildlife Service (FWS) and the Department of Fish and Game own the restoration sites. Public access and recreation that can be accommodated consistent with state and federal regulations include hunting, fishing, wildlife viewing, photography, environmental education, and interpretation. While these agencies are dedicated to providing high-quality recreational opportunities as part of the Restoration Project, there is the potential for conflict between the goals of restoring and managing habitat for wildlife and providing public access (Stolen 2003, Delong 2002). It is well-known that human disturbance can have a range of impacts on individuals, species, communities and ecological functions.

This section focuses on understanding the impacts of public access species on these species of greatest concern to the Project: **birds**, including the California clapper rail, California least tern, snowy plover, and migratory and resident waterbirds; **mammals**, including salt marsh harvest mice and harbor seals; **aquatic life**, especially native fish and the native oyster (*Ostrea lurida*); and **vegetation**, especially rare plants and vegetation communities in low, mid-, and high marsh and the upland transition.

What do we know about this issue as it relates to the Project?

There is a very large body of literature on the effects of human disturbance on species, especially waterbirds. Literature reviews in the field include summaries of hunting impacts on waterbirds (Belanger and Bedard 1995, Madsen and Fox 1995, Bell and Fox 1991), disturbance effects on nesting colonial waterbirds (Carney and Sydeman 1999) beach nesting birds (Burger 1995), recreation disturbance effects on waterbirds and mitigation measures (DeLong 2002), ecological effects of human trampling on soils (Hammitt and Cole 1998) and vegetation (Cole and Hammitt 1998, Liddle 1975), and effects of recreation on fish and mammals (Hammitt and Cole 1998). Two books provide a comprehensive overview of recreation effects on wildlife, vegetation and ecological conditions as well as management recommendations (Knight and Gutzwiller, eds. 1995, Hammitt and Cole, eds. 1998). In her review of disturbance to waterbirds, DeLong (2002) notes that there has been significant research into these human disturbance factors: “hunting, boats, pedestrians, researchers, anglers, aircraft and general recreational activities (listed in decreasing order of citations)”.

Knight and Cole (1991) developed a conceptual framework for this issue showing general categories of disturbance and responses by individuals, populations and communities (Figure 1). Disturbance types are often divided into two broad categories: consumptive, including hunting, fishing and some research, and non-consumptive, including wildlife viewing, hiking boating, and some types of research. Specific actions or activities likely to be part of the Restoration Project are listed under the four impact categories in Figure 1. Knight and Cole (1995) and Cole and Landres (1995) review the direct and indirect effects of human disturbance on wildlife. Direct effects can include behavioral changes, especially flight and foraging times, physiological changes due to stress, changes in reproductive productivity, and death. These direct effects can lead to changes in distribution, abundance, and diversity of species. Indirect effects include habitat loss due, for example, to vegetation trampling, soil compaction, hunting, and spread of non-native species; community composition changes due, for example, to feeding; and increased predation rates due, for example, to predators following people to nesting areas. Knight and Temple (1995) divide learned behavioral responses of wildlife into three categories: avoidance, attraction and habituation. Human disturbance can result in any of these reactions, depending on the species or individual.

Some effects are easily observed, especially flight responses or changes in foraging activity. Changes in distribution, abundance and local diversity are also relatively easy to quantify. Decreased reproduction, especially due to changes in nest distribution, nest abandonment, and loss of eggs and chicks to predation have been documented in colonial and solitary nesters. Effects on vigor, especially energetics of waterbirds, have not been well documented and represent an important research area (Knight and Cole 1995). Disturbance effects migratory species productivity are also difficult to determine (Fox and Madsen 1997).

Birds. Waterbirds have been the subject of hundreds of research articles reporting on the effects of human disturbance. Most research has investigated changes to behavior, productivity of resident species, and the distribution, diversity and abundance of species. Common recommendations to reduce impacts include adequate avoiding the activity, buffer zones, social carry capacities and refuges of adequate size and quality to allow animals an undisturbed area.

Breeding Birds. Researchers agree that breeding birds are very sensitive to human disturbance, whether the disturbance is from trail use, boats, or research (Carney and Sydeman 1999, Burger and Gochfeld 1993, Keller 1991, Burger 1981, Anderson and Keith 1980). Most disruptive activities include scientific research requiring visiting nests, loud cars and boats, and direct approach of any kind. Burger (1995) found that simultaneous recreational activities can result in habitat loss as birds abandon an area, increased predators, mortality and decreased reproductive success. Researchers report negative effects on colonial nesting species, solitary nesters, breeding adults and juveniles. Sensitivity to disturbance varies widely within and between species depending on location, time of year, type of disturbance, ability to habituate and proximity of approach. Impacts can be lessened or eliminated, depending on the species, by avoiding disturbance early in the nesting season, avoiding certain times of day, limiting chick handling, and moving slowly inside colonies. Still, the invasive nature of some activities means that negative impacts on nesting species may occur unless disturbance is avoided altogether.

Non-breeding Birds. Studies of human disturbance to non-breeding shorebirds, waterfowl and colonial waterbirds have quantified responses--especially flight distance, foraging times, species diversity, abundance and distribution--to pedestrian approach, non-motorized vehicles, motorized vehicles, hunting and fishing. These studies show that bird responses vary based on a number of factors: proximity of approach, species, time of year, habituation, location, speed of movement, and type of recreational activity. In general, the faster and louder the approach, the further away birds will flush. Many studies show that tangential approaches to birds rather than direct approaches cause less disturbance (Rodgers and Schwikert 2003).

Trail users and landside recreational activities can cause a range of effects, depending on a number of factors. Direct approaches by people on foot are very disruptive causing flight and reduced foraging times in a many shorebird species compared to undisturbed birds (Thomas, et al. 2003, Klein 1993, Burger and Gochfeld 1993). Habituation is an important factor in whether birds respond to non-threatening human disturbance. Habituation is such a major factor in bird behavioral responses that Nesbit (2000) has suggested slowly habituating birds in new recreation areas to decrease significant disturbance effects.

Rodgers and Schwikert (2002, 2003) also showed at waterbirds flushed at significantly longer distances when approached by with faster and noisier airboats as compared to slower, less noisy outboard motorboats. In addition, larger birds flushed sooner than smaller species, no matter what the boat type, probably due to their slower take-off times.

Anglers have been shown to disturb birds and prevent them from using foraging habitat. However, the degree of disturbance typically depends on the number and location of anglers. Hunting, a consumptive and traditional use, has been shown to significantly effect bird behavior and species distribution and abundance. It is widely considered one of the most disruptive recreational activity, affecting target and non-target species alike (Paillisson, et al. 2002, Fox and Madsen 1997).

Mammals. *Salt Marsh Harvest Mouse*. There were no articles on human disturbance and salt marsh harvest mice. However, this species' dependence on pickleweed vegetation and high marsh/transition zone refugia, make it vulnerable to vegetation trampling from people and dogs going off trail or boaters leaving their boats and trampling vegetation. Feeding other rodents may increase the populations of competitive species (Hammitt and Cole 1998). New trails may provide predator access or attract more predators that the pre-access condition. The location of boardwalks or new trails could fragment habitat. Dogs could kill or harass mice.

Harbor Seals. In San Francisco Bay, recreational boating is the primary source of behavioral changes, particularly haul-out patterns, in the Pacific harbor seal (Farallones Marine Sanctuary Association 1999). The effects of disturbance range from mild to severe, from a hauled-out seal raising its head at the sound of a disturbance to, in the most extreme cases, mortality of adults or pups. Harbor seals are vulnerable to "harassment by persons on shore and boaters and kayakers from [San Francisco] Bay" and "will flush from haul-out sites at 300 meters" (Lidicker and Ainley 2000, 245). Kayakers cause a greater disturbance to seals than powerboat operators do because of their ability and tendency to travel close to the shoreline, where seals may be hauled out (Suryan and Harvey 1999). Because harassment increases seals' energy expenditure by decreasing haul-out period, harassment has the greatest impact on nursing pups and molting adults, when haul-out is most critical (Suryan and Harvey 1999). If disturbed too often, seals may abandon haul-out sites entirely (Marine Mammal Center 2002). Boats that travel at a slow, steady pace and parallel to haul-out sites cause fewer disturbances than boats moving towards and lingering near the seals (Suryan and Harvey 1000). Public access, especially via boat, can bring dogs in close proximity to harbor seals. Dogs can harm seal pups and harass adults, and some diseases of dogs can be transmitted to harbor seals (NOAA n.d.).

Fish and Oysters. Angling, a consumptive, traditional use, causes direct mortality to fish through catch and the introduction of native and non-native species for fishing (Hammitt and Cole 1998). Stocking fish for anglers can change the composition of fish communities and changes in ecosystem dynamics, especially when a predator or highly successful competitor is introduced.

Boating activities also degrade fish habitat by increasing turbidity (Crawford 1998), disturbing aquatic vegetation and adding pollution due to boat engines (Balk et al. 1998). In particular, the two-stroke outboard boat engine produces toxic emissions with substances that have an extremely negative impact on fish, particularly juveniles (Balk et al. 1998). Human waste and trash generated by boats can eutrophy and pollute fish habitats (Hammitt and Cole 1998). While no articles addressed the impacts of recreation on oysters, these impacts of boats are also applicable to native oysters, which are especially sensitive to siltation (Nichols and Pamatmat 1988).

Vegetation. The very large body of literature on human disturbance and vegetation shows that trampling, erosion, water pollution from erosion and increased runoff are all significant impacts of public access (Hammitt and Cole 1998). Specific impacts to plants come from trampling or vehicles that reduce the cover of low growing marsh plants and destroy rare plants. Trails are known to provide corridors for the spread of non-native plants.

What is the level of certainty of our knowledge?

Researchers have shown that wildlife responses are varied and often unpredictable (Rodgers and Schwikert 2003, Hammitt and Cole 1998). Thus, predicting the specific responses of particular species in a particular place is not possible. Data must be collected specific to the location, time of year, species, and individuals to understand responses to particular recreational activities. However, based on a large number of studies in different locations and different species, researchers are certain of some general principles:

- Direct approach to individuals has a greater impact than tangential approach.
- The loader and faster the vehicle, the greater the response wildlife will have.
- The closer the approach, the more likely individuals will stop their non-alert activities and

eventually flush or flee.

- Flushing birds or mammals from breeding sites increases chances of offspring mortality.
- Consumptive uses, such as hunting and some research, have the greatest effects on wildlife including death, reduced productivity, and loss of foraging and nesting habitat.
- Any type of human visit can disturb wildlife causing direct and indirect effects from behavioral change to death; however, for many activities, specific mitigation measures, especially avoidance and adequate buffer distances, can reduce or eliminate the effect.

Some areas of uncertainty:

- How important is this habituation in changing species behavior? Can gradual habituation of species to non-threatening activities reduce the impact of access into a new area? What species do not respond to habitatuation?
- How does human disturbance impact the energetics and physiological reactions of individuals? To what degree do these impacts have consequences for survival and reproduction?
- To what extent does human disturbance affect wildlife population dynamics?
- How effective are mitigation measures and how does their effectiveness change over time with changes in recreation or wildlife experiences?

What predictive tools exist for gaining an understanding of this issue and what tools are needed to reduce uncertainty to an acceptable level?

Predicting impacts to species and ecosystems from human disturbance is extremely difficult. Predictions are hampered by the difficulty in distinguishing between variations resulting from human impacts and those due to natural processes. In addition, animal responses to impacts vary based on a large number of factors. Because wildlife responses are influenced by so many variables, data gathered in any particular area or at any particular time are not predictive of animal responses elsewhere or even at the same place at a later date (Rodgers and Schwikert 2003). Wildlife responses to human disturbances are not uniform or consistent (Hammitt and Cole 1998).

Currently, studies of human disturbance use statistical methods as the primary tools to assess disturbance effects, such as t-Tests, regression, ANOVA, CANOVA, MANOVA and non-parametric techniques for non-normal data such as the Mann-Whitney U-Test. Rodgers and Schwikert (2003) recommend stimulus-response experiments to determine when and how individuals respond to different disturbances. But, they state that responses are so unpredictable that “local data should be collected to calculate site-specific buffer distances’ to prevent disturbance; “conservation personnel should monitor changes in species composition at regulated sites to adjust buffer distances to reflect the presence of new, more sensitive species”; and buffer zones should be evaluated periodically to determine their effectiveness and corrective measures taken based on data from control sites or sites before disturbance. Given these recommendations, modified Before-After-Control-Impact (BACI) studies (Underwood 1994) should be used to evaluate the effectiveness of all protective measures, evaluate wildlife responses in previously inaccessible areas, and provide greater power in separating natural variation from human-caused responses. Such studies may produce greater predictive capabilities.

What are potential restoration targets and performance measures, linked to the Objectives, for evaluating the progress of the restoration project?

Restoration targets are the standards, based on scientific data, for successfully achieving Project Objectives. Restoration targets for species behavior, distribution, abundance and diversity, as well as ecosystem function targets, should come from Issues 1, 2 and 3.

Performance measures are parameters or metrics used to assess progress toward the restoration targets. Performance measures that can be used to assess the impact of human disturbance on ecological Project Objectives include: flight distance of individuals, activity budgets of individuals, species diversity and abundance, nesting and breeding success, predation rates, presence/spread of predators and non-native species, area of vegetation trampled, amount of erosion due to off-trail excursions, numbers of recreationists/visitors and their activities, amount of trash improperly disposed of, numbers/length of "social" trails, incidences of wildlife feeding/numbers of animals approaching visitors for food.

What key questions essential to the success of the restoration need to be addressed through further studies, monitoring, or research?

For Part 1 of Issue 9, the most important research topics include:

- BACI studies for surface and water trails for shorebirds, waterfowl and harbor seals;
- BACI studies for surface and water trails for clapper rails, salt marsh harvest mice and snowy plovers, in large animal population areas or when species have recovered to an acceptable level;
- Disturbance effects of landside and water trail recreation on roosting birds;
- Water trail effects on harbor seals;
- Success of various management methods in reducing or preventing impacts-- methods such as buffer distances, observation blinds, or social carrying capacities;
- Changes in public attitudes toward Restoration Project access and recreational uses.

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