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## **NAPA RIVER SALT MARSH RESTORATION**

### **HABITAT RESTORATION PRELIMINARY DESIGN PHASE 2 STAGE 2 OF THE HYDROLOGY AND GEOMORPHOLOGY ASSESSMENT IN SUPPORT OF THE FEASIBILITY STUDY**

#### **FINAL REPORT**

Prepared for

The California State Coastal Conservancy

Prepared by

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## NAPA RIVER SALT MARSH RESTORATION GLOSSARY AND ABBREVIATIONS

### **Breach**

An excavation through an earth levee through which tidal exchange is provided to and from the pond.

### **Borrow ditch**

Human-constructed channels adjacent to levees that tend to be straighter and offer less habitat complexity than natural channels.

### **Damping (tidal damping)**

A decrease in tidal range at a location due to frictional losses between the location and the boundary tide.

### **CDFG**

California Department of Fish and Game.

### **Ditch block**

Earth fill that crosses an existing borrow ditch to inhibit flow.

### **EIR/EIS**

Environmental Impact Report / Environmental Impact Statement.

### **Fetch (wind fetch)**

An area of open water over which wind blows to generate waves.

### **Fringe marsh**

Vegetated high marsh, typically formed within the last century, that borders and forms the edges of slough channels.

### **MHHW**

Mean higher high water.

### **MLLW**

Mean lower low water.

### **Morphology**

Shape and structure of an object.

### **Muting**

Reduction of the tide range caused by undersized inlets or engineering structures that limit the volume of water as the tide wave passes from more open water. The degree of muting is a function of the relative sizes of the inlet and estuary.

### **NAVD88**

North American Vertical Datum of 1988. Fixed vertical geodesic datum established in 1988 to replace NGVD 29.

### **NRSMR**

Napa River Salt Marsh Restoration

### **Ppt**

Parts per thousand. A measure of concentration.

### **RTAG**

Restoration Technical Advisory Group

### **Slough**

In general use, a tidal channel. In this project the term is used to refer specifically to the major (named) tidal channels between the ponds (e.g., South Slough, Dutchman Slough, etc.).

### **Subsidence**

The consolidation and lowering of a ground elevation.

**Thalweg**

The deepest point or a line joining the deepest points of a stream channel.

**Tidal damping, see Damping.**

**Tidal Frame**

The elevation range of the tides.

**Tidal prism**

Volume of water that flows into or out of an area during the diurnal tide.

**USACE**

U.S. Army Corps of Engineers

**Water year (WY)**

Year defined by the hydrologic cycle. Begins on October 1.

# 1. INTRODUCTION

## 1.1 BACKGROUND

The California State Coastal Conservancy (Conservancy), U.S. Army Corps of Engineers, San Francisco District (USACE) and the California Department of Fish and Game (CDFG) propose to restore a mosaic of tidal wetland and managed pond habitat at the 9,460-acre Napa River Unit of the Napa Sonoma Marshes Wildlife Area (Figure 1). The site consists of 6,370 acres of inactive salt ponds and nearly 3,500 acres of remnant tidal sloughs and wetlands.

Historically, the project site was part of an extensive complex of tidal marshes along the northern border of San Pablo Bay. Beginning in the 1850s, most of the site was diked and drained for agricultural use. In the 1950s, the diked areas were converted to salt production ponds. In the early 1990s, the former salt pond operators, Cargill Inc., ceased salt production and sold the land to the State of California. CDFG currently owns and manages the site.

Restoration of the project site has long been a high priority for local resource agencies and the environmental community. The restoration would be significantly larger than any other completed in San Francisco Bay and one of the largest on the west coast of the United States. The restoration of tidal and pond habitats at the site is ecologically important to San Francisco Bay, providing habitat to fish and wildlife, including endangered species, migratory waterfowl, shorebirds, and anadromous and resident fish.

A Feasibility Study for restoration was initiated in 1998 and is being undertaken by the USACE (federal sponsor) in conjunction with the Conservancy and CDFG (non-federal sponsors). The purpose of the Feasibility Study is to “identify a feasible project which fulfills the Federal interest requirements and meets the needs of the non-Federal sponsor. Project feasibility is assessed in terms of physical, environmental, and economic considerations” (USACE, 2002). Additional discussion of the purpose and need for the project is included in the Napa River Salt Marsh Restoration Project Environmental Impact Report/Environmental Impact Statement (EIR/EIS) (JSA, 2002).

The Feasibility Study alternatives formulation and comparison considered a matrix of combinations of habitat restoration options and salinity reduction options. A project alternative consists of a particular combination of restoration and salinity reduction options. This study focuses on the habitat restoration options. See the Feasibility Study, EIR/EIS, and PWA (2002b) for discussion of salinity reduction options.

PWA focused on the tidal marsh restoration design. CDFG will prepare the restoration design for the managed ponds based on target pond depths and salinity to attract waterfowl and shorebirds. In general, after salinity reduction, restoration of managed pond habitat consists of operating and maintaining hydraulic control structures and levees. Installation of the control structures and initial levee

improvements are both part of the salinity reduction phase. Ponds will be managed to create shallow and deep open water habitat, with varying levels of salinity.

After PWA completed the majority of the present study, two small breaches were constructed in Pond 3. Therefore, their effects on the restoration project are discussed separately in Appendix D. The remainder of the report assumes pre-breach site conditions. The first of these two small hand-dug breaches was discovered by CDFG on August 12, 2002 along the Pond 3 levee to South Slough. CDFG constructed a second emergency breach at the southeast corner on Pond 3 on September 9, 2002 to reduce the potential for failure of the siphon that connects Pond 3 to hypersaline water in Pond 4. Overall, these small breaches do not affect the preliminary design described in this report. However, the breaches make it necessary to monitor site conditions and adjust the implementation plan as needed. In addition, the breaches affect the description of the "no project" alternative in the Feasibility Study and the EIR/EIS and accelerate the need for Pond 3 monitoring and adaptive management. These considerations are discussed in Appendix D.

## 1.2 PURPOSE, SCOPE, AND REPORT ORGANIZATION

This report documents the preliminary restoration design of the Napa River Salt Marsh Restoration (NRSMR) project and supporting hydrologic and geomorphologic analyses conducted by PWA. The supporting analyses are comprised of: preliminary restoration design, hydrodynamic modeling of the restoration options, sediment budget of North San Francisco Bay, and hydro-geomorphic modeling of restored tidal wetland habitat evolution. These studies were conducted concurrent with the Feasibility Study and EIR/EIS assessment of restoration alternatives and provided input to these processes in an iterative fashion. This study is part of a series of hydrology and geomorphology analyses conducted by PWA in support of the Feasibility Study. The sediment budget and habitat evolution assessments update those previously presented (PWA 2002b) as discussed below.

The preliminary restoration design analysis defines the restoration design elements based on geomorphic principles and assessment of potential impacts and benefits. Hydrodynamic modeling was conducted to simulate project performance, assess potential hydrologic impacts, and modify the design to avoid impacts as possible. The modeling provided input to the sediment budget and habitat evolution assessments. The sediment budget analysis gauges the demand for sediments presented by restoration of the Napa salt ponds and provides an indication of whether the supply is sufficient to meet this demand without adversely impacting other wetlands in the immediate region. The hydro-geomorphic modeling incorporates the results of the sediment budget and hydrodynamic modeling to predict restored tidal wetland habitat evolution. These predictions were prepared for each restoration option and provide a consistent means of comparing between them for alternatives selection.

The remainder of this report consists of the following:

- Section 2: Project goals
- Section 3: Opportunities and constraints for restoration
- Section 4: Preliminary design of the habitat restoration options

- Section 5: List Of Report Preparers
- Section 6: References
- Appendix A: Hydrodynamic Modeling
- Appendix B: Sediment Budget
- Appendix C: Expected Habitat Evolution

### 1.3 PREVIOUS STUDIES AND REPORTS

This report is being released concurrently and in conjunction with two key NRSMR planning documents:

- Napa River Salt Marsh Restoration Draft Feasibility Study (USACE, 2002)
- Napa River Salt Marsh Restoration Draft Environmental Impact Report/Environmental Impact Statement (JSA, 2002)

There have been numerous studies and reports pertinent to the NRSMR project. The Feasibility Study and Environmental Impact Report/Environmental Impact Statement (EIR/EIS) provide lists and discussions of prior studies and reports covering: physical and modeled analysis (hydrodynamic and geomorphic analysis, water quality and sediment characterization, and baseline monitoring of Pond 2A tidal restoration project); biological analysis; and management plans and strategies.

This study is one in a series of hydrologic and geomorphic analyses conducted by PWA for the USACE, Conservancy, and California Department of Fish and Game:

- *Phase 1: Hydrodynamic model development and modeling of existing conditions (PWA, 2002a)*  
The existing physical conditions characterized in Phase 1 include parameters such as water surface elevation, and salinity transport and sediment transport, using a combination of one- and two- dimensional computational modeling. One-dimensional (1-D) computational modeling is used to describe the predominantly 1-D flow through the network of slough channels and rivers (the Napa River and Sonoma Creek), and two-dimensional (2-D) computational modeling is used to describe the predominately 2-D mixing processes in the former salt ponds. The setting of the site, including the history of past management of the salt ponds, the restoration initiative and the current management of the salt ponds is described in the Phase 1 report (PWA, 2002a).
- *Phase 2 Stage 1: Screening-level salinity reduction modeling, preliminary sediment budget, preliminary habitat evolution estimates, geotechnical sampling (PWA, 2002b)*  
The hydrodynamic model produced in Phase 1 was further modified and developed under Phase 2 Stage 1 to undertake salinity reduction alternative modeling. This phase also included a preliminary sediment budget of the North San Francisco Bay (San Pablo Bay) and initial estimates of habitat evolution for various habitat restoration options.

- *Phase 2 Stage 2: Preliminary restoration design (this report), final salinity reduction modeling, water quality modeling*

The final salinity reduction modeling and water quality modeling are in process and will be documented separately.

The sediment budget and habitat evolution analyses components of the current study (Phase 2 Stage 2) were begun in Phase 2 Stage 1. They have been revised and refined in the current study to reflect the final habitat restoration options and preliminary designs, and to incorporate new information from the hydrodynamic modeling of restored conditions. In addition to the studies listed above, PWA has assisted with Napa siphon field data collection (PWA, 2001a) and project scoping (PWA, 2001b).

Our studies are closely connected to and draw upon other recent projects, including:

- Extensive hydrologic and suspended sediment data collection by the U.S. Geological Survey and University of California, Davis between September 1997 and March 1998 (Warner, 2000). These data were used to provide boundary data for the existing conditions model and for calibration and validation purposes of the 1-D computational model of the slough channels, Napa River, and Sonoma Creek.
- Digital Terrain Model (DTM) by Towill, Inc. The DTM included the slough channels, rivers, salt ponds and marshplains of the site. (Towill, Inc., 2001). The DTM was used by PWA to construct the geometrical information required for the hydrodynamic model.
- GIS mapping of historical Napa Marsh channels for the San Francisco Estuary Institute (1999). This mapping was used in restoration design and prediction of habitat evolution.

#### 1.4 PLANNING PROCESS

The restoration design was developed in close coordination with the project sponsors – the Conservancy, USACE, and CDFG. It ultimately reflects the ideas and direction of PWA and project sponsor staff, specifically: from the Conservancy, A. Hutzler and N. Hitchcock; from the USACE, L. Galal, S. Nicholson, S. Von Rosenberg (GAIA Consulting, Inc.), C. Conner, P. Mull, and B. DeJaeger; and from CDFG, L. Wyckoff, J. Swanson, T. Huffman, and M. Rugg. In addition, input from other project consultants is acknowledged: K. Mackay and B. Norton of Jones & Stokes, and M. Beutel and B. Faisst of Brown & Caldwell.

The design process also benefited significantly from input from the Napa Sonoma Marsh Restoration Group and the Restoration Technical Advisory Group (RTAG). The NSMRG is a stakeholder group consisting of resource agencies, regulatory agencies, other entities conducting restoration projects in the North Bay, researchers, environmental groups, and private citizens that has met throughout the development of this project. The RTAG is a subset of the NSMRG. We wish to acknowledge the RTAG members: P. Baye of USFWS, J. Collins of SFEI, J. Lament of Ducks Unlimited, D. Schoellhamer of the USGS, C. Wilcox of CDFG, and S. White of Sonoma County Water Agency (SCWA).

## 2. PROJECT GOALS

Project goals defined by the project sponsors early in project development provided the basis for formulation of more detailed design criteria and detailed design by restoration option in the current study. Regional goals, overarching project goals, and specific project goals presented in Sections 2.1, 2.2, and 2.3 below are taken from a draft of the Feasibility Study.

### 2.1 REGIONAL GOALS

Regional habitat goals for the North Bay were used as a basis for defining the project goals (Section 2.1.2). Regional goals were taken from the *Baylands Ecosystem Habitat Goals Report* (the Goals Report). The Goals Report was a multi-agency regional planning effort defining the habitat restoration goals for the entire Bay Area. As stated in the Goals Report (p. 97):

The overall goal for the North Bay is to restore large areas of tidal marsh and to enhance seasonal wetlands. Some of the inactive salt ponds should be managed to maximize their habitat functions for shorebirds and waterfowl, and others should be restored to tidal marsh. Tributary streams and riparian vegetation should be protected and enhanced, and shallow subtidal habitats (including eelgrass beds in the southern extent of this subregion) should be preserved or restored.

Tidal marsh restoration should occur in a band along the bayshore, extending well into the watersheds of the subregion's three major tributaries – Napa River, Sonoma Creek, and Petaluma River. Seasonal wetlands should be improved in the areas that are currently managed as agricultural baylands. All remaining seasonal wetlands in the uplands adjacent to the Baylands should be protected and enhanced.

... In total, the Goals for the North Bay subregion call for increasing the area of tidal marsh from the existing 16,000 acres to approximately 38,000 acres, and creating about 17,000 acres of diked wetlands managed to optimize their seasonal wetland function.

In addition to the overall North Bay goals, the Goals Report also provides more specific regional goals. The recommendations for the Napa River Area and Sonoma Creek applicable to the project area include the following (pp. 106-109):

- Restore large areas of tidal salt marsh along both sides of the Napa River, including former salt ponds and Cullinan Ranch.
- Manage the remaining inactive salt ponds on both sides of the Napa River as salt pond or shallow, open water habitat to support waterfowl.

## 2.2 OVERARCHING PROJECT GOALS

It should be noted that the overarching goals are ecosystem-focused rather than species-focused. The overall goal of the project is to enhance a variety of wetland habitats for a broad range of species. The overarching project goals are as follows:

- Restore a mosaic of diverse habitats that will benefit a broad range of fish, wildlife, and plant species, including endangered and threatened species, fish and other aquatic species, and migratory shorebirds and waterfowl.
- Restore natural, self-sustaining systems that can adjust to naturally occurring changes in physical processes, with minimum ongoing intervention, and that will change over time due to inherent dynamic characteristics of an estuarine system.
- Conduct the habitat restoration in phases, using adaptive management techniques, and coordinate the restoration with restoration projects throughout the Napa-Sonoma Marshes, particularly Cullinan Ranch and Skaggs Island.
- Meet as many of the goals and objectives of the *Baylands Ecosystem Habitat Goals Report* as feasible, focusing on how this project's goals and objectives fit within the entire North Bay region.
- Evaluate the restoration from a regional perspective, as not all regional objectives can be addressed within the project boundaries.

## 2.3 SPECIFIC PROJECT GOALS

These specific project goals for the Napa River Unit of the Napa Sonoma Marsh State Wildlife Area were developed by the Conservancy, CDFG, and the USACE, based upon the overarching goals of the project and the regional goals from the *Baylands Ecosystem Goals Report*.

- Create a mix of tidal habitat and managed pond habitat to serve a broad range of wildlife, including endangered and threatened fish and other aquatic species, and migratory shorebirds and waterfowl.
- In a phased approach, restore large areas of tidal habitats in a band along the Napa River to maximize benefits for fish and other aquatic animals, and ensure connections between the patches of tidal marsh (within the project site and with adjacent sites) to enable the movement of small mammals, marsh-dependent birds, and fish and aquatic species.
- Improve the ability to manage water depths and salinity levels in the managed ponds to maximize feeding and resting habitat for migratory and resident waterfowl and shorebirds.

These specific project goals guided the development of project alternatives. Both the specific project goals and the overarching project goals were reviewed by the NSMRG.

### 3. OPPORTUNITIES AND CONSTRAINTS FOR RESTORATION

This section describes the existing conditions affecting tidal wetland restoration – restoration opportunities and constraints, with a focus on physical and geomorphic conditions. Existing conditions at the site have been documented previously in the Feasibility Study, EIR/EIS, and in PWA reports (2001a, 2001b, 2002a, 2002b). These conditions are summarized here within the context of restoration feasibility and approach.

#### 3.1 OPPORTUNITIES

*Hydrologic connection to tidal waters.* The lower Napa River is a relatively large tidal water body and pond inundation can be achieved through direct breaching to the river. Hydraulic modeling (Appendix A) shows that the slough channels are sufficiently sized to convey tide waters to Ponds 3, 4, and 5, with no noticeable tidal damping. Tidal exchange to Ponds 6, 6A, and 2 East has not been modeled. Tidal exchange may be somewhat reduced to these ponds.

*Suspended sediment supply.* Since the pond bottoms are subsided below natural marshplain elevations (see Constraints below), sedimentation may be relied upon to raise ground elevations. Sediment laden inflow from San Pablo Bay and Carquinez Strait provides a source of tidal sediments and large floods on the Napa River provide an adjacent fluvial sediment supply. Sediment supply is discussed further in Appendix B.

*Natural vegetative processes.* Marsh vegetation along the channels and in Pond 2A is expected to provide a source of seed and propagules for natural colonization of the restored marshes without planting.

*Existence of antecedent channels.* Antecedent historic channels are present in all the ponds proposed for tidal restoration. Figure 2 shows the historic channel configuration. These channels are probably filled with somewhat consolidated sediments but are expected to scour preferentially within the remnant marshplain once the ponds are breached. The extent of sediment consolidation and resistance to erosion are not well known and show some seasonal variability. Soil samples collected by PWA late in November of 2001 indicated a relatively hard and salty crust exists at the surface, with the exception of Ponds 1, 1A, and 2A. However, visual observations by CDF suggest that this hard crust was less extensive the following spring in April 2002 (pers. comm., Larry Wyckoff, CDFG). Scour is expected to occur first nearest the breaches, gradually headcutting back into the pond interior.

The exact timeframe for channels to complete scour is not known. Channels inside Pond 2A scoured rapidly, with what appears to be complete channel scour observed at several locations within six years of breaching (PWA, 2002c). Monitoring of channel scour at Cooley Landing in the South Bay suggests longitudinal scour (headcutting) rates of as high as 600 to 800 feet over the first seven months, or 1,000 to 1,400 feet/year (PWA, 2002d). These are initial rates and are expected to decrease over time. However, internal channel erosion rates at the Napa River Unit ponds to be restored may not be as high as those

observed at Pond 2A and Cooley Landing because of differences in the channel sediments. Unlike Pond 2A and Cooley Landing, the ponds proposed for restoration at Napa have all been drained and used for agriculture. Drainage of sediments causes soil compaction and makes the sediment more resistant to erosion. In addition, unlike Pond 2A and Cooley Landing, the Napa ponds have higher salinity levels, which can cause an erosion-resistant crust of gypsum to form (see Constraints section below). Channel re-establishment is expected to occur more readily in the more deeply subsided ponds. Channel re-establishment at Ponds 3, 6, and 6A, which are higher in elevation, may take longer than at Ponds 2, 4 and 5, which are more deeply subsided.

*Grading or fill to elevations conducive for marsh vegetation establishment.* Grading, such as lowering levee crests to marshplain elevations, and filling can be used to create areas likely to be colonized with marsh vegetation within only a few years. Material dredged from onsite slough channels or regional dredging projects could provide a larger source of fill for placement, as needed.

*Connectivity with existing marsh.* Restored tidal areas will connect to significant areas of existing marsh habitat, providing large areas of contiguous habitat for use by fish and wildlife.

### 3.2 CONSTRAINTS

*Subsided ground elevations below vegetation colonization elevations.* The bottom elevations for all ponds proposed for tidal restoration are subsided below natural marshplain elevations, and in most cases are initially too low in the tidal frame for marsh plants to establish or survive. They are subsided below the elevation of Pond 2A when it was breached in 1995, then rapidly colonized with marsh vegetation. Figure 3 compares initial elevations of restored tidal wetland sites in San Francisco Bay to the time it took each site to reach 50% vegetative cover. The average Napa River salt pond bottom elevations are shown on this figure for comparison. Restoration of tidal marsh at the Napa River ponds will require either fill or accepting a longer timeframe, as natural estuarine sedimentation raises site elevations.

Figure 4 shows representative site elevations for Ponds 2, 2A, 3, 4, 5, 6, and 6A. This is gross bathymetry; micro-topography is not shown. Elevations are color coded to correspond with approximate vegetation colonization zones. Areas shaded in dark green – primarily Pond 2A and the fringing marsh areas – are at elevations at which mid-marsh vegetation is expected to colonize rapidly. The high elevations at Pond 2A are consistent with the rapid marsh development observed at this pond after breaching (elevations have changed little between the time of breaching and the time of this bathymetry). Areas in medium green – parts of Pond 3 – are expected to colonize with low marsh vegetation over approximately 10 years. Areas in light green – most of Pond 3, major parts of Ponds 6 and 6A, and small parts of Ponds 4 and 5 – are expected to colonize with low marsh vegetation slowly, through lateral expansion of rhizomes from the higher areas. Areas in light and medium brown – most of Ponds 4, 5, and 2, as well as parts of Ponds 3, 6, and 6A – are expected to be intertidal mudflat until sedimentation raises the subsided ground elevations. Dark brown areas will be subtidal habitat unless sedimentation occurs.

*Sediment supply limitations to sedimentation.* Sediment supply is expected to be highest at Pond 3, decreasing with distance upstream on the Napa River (Ponds 4 and 5) and with distance from the Napa River itself (Ponds 2, 6, and 6A).

*Wind wave resuspension limitations to sedimentation.* The ponds are large and high wind fetches will allow relative large waves to generate within the ponds. If the wind fetch is not reduced in the design, high wave activity is likely to limit rates of sedimentation by maintaining sediments in suspension and resuspending previously deposited sediments (Appendix C).

*Loss of existing habitat.* The design must minimize loss of existing marsh habitat during construction and subsequent site evolution. Breaches must be located away from areas of wide fringing marsh, as possible, to minimize the need to excavate pilot channels through the marsh. Some loss of fringing marsh is expected to occur after breaching through erosion and enlargement of the slough channels in response to the increased tidal prism. This loss must be accounted for in project planning, such as by lowering levees to maintain marsh connectivity along the channels, use of fill placement, and/or considered an acceptable transitory impact.

*Limitations to natural channel formation.* In general, breaching at the locations of historic channels is expected to help re-establish the antecedent historic channels. In addition to sediment compaction (discussed in Opportunities above), there are two additional sources of potential resistance to re-establishment of the natural channels: existing borrow ditches and the presence of a gypsum layer on the pond bottom. Borrow ditches can short-circuit the tidal flow, drawing tidal energy away from scour of the natural channel system. Gypsum is a hard calcium precipitate that forms when pond water salinities exceed approximately 150 ppt. The presence of a gypsum layer on the pond bottom may impede channel development. Ponds 6 and 6A are believed to have a thin crust of gypsum on the pond surface. Gypsum is expected to be negligible at the other ponds proposed for tidal restoration. Thicker layers of gypsum may exist at some of the ponds proposed for managed pond restoration, such as Ponds 7, 7A, and 8, due to their higher salinity levels.

*Flooding and infrastructure.* Existing infrastructure is shown on Figure 5. There are also boat facilities and a wastewater treatment plant outfall downstream, navigation on the Napa River, and homes upstream along the Napa River. The design must avoid or mitigate for impacts to existing infrastructure. Similarly, the project must avoid or mitigate for flood impacts to adjacent infrastructure. Impacts to some existing infrastructure, such as the PG&E power towers that traverse Pond 3, have been addressed in the preliminary design. Others will be addressed in final design.

*Levee stability.* Breaching selected ponds for tidal marsh restoration is expected to result in widening and deepening of the slough channels in response to increased tidal flows. In some areas, levees needed for flood protection or to maintain managed pond habitat could be threatened. The project must avoid and/or mitigate for any impacts to levee stability. (Cullinan Ranch levees are discussed separately below.)

*Difficult construction access.* The ponds proposed for tidal restoration are inaccessible by road, requiring boat transport for construction equipment and crews. In addition, the soft bay muds make construction with conventional equipment impractical.

*Pond and tidal channel sediment characteristics.* Once tidal action is restored, sediments are expected to scour from the antecedent channels and to a much lesser extent from the remnant marshplain surface. These sediments will be resuspended and deposited at other locations, including in existing marsh and channel habitat. Any contaminants in the mobilized sediments will also be transported. The project must avoid and/or mitigate for any environmental impacts associated with transport of sediments.

*Unprecedented large project size.* While the large size of the potential restoration is a significant benefit, the unprecedented size of the project also makes it more difficult to predict tidal habitat evolution and regional impacts based on the evolution of previous smaller restorations in San Francisco Bay. A project of this magnitude has the potential to affect regional processes such as sediment budget and hydrodynamics, and for processes such as wind wave resuspension, which are less significant at smaller sites, to play a larger role. Even so, the scale of the project with respect to regional hydrodynamics and sedimentation are often no greater than previous interventions such as dredging of the Mare Island Shipping Channel or than natural fluctuations in these processes. The unknowns associated with the magnitude of the project may be addressed in the design through phasing, monitoring, adaptive management, and flexible project goals.

*Proposed Cullinan Ranch restoration.* Cullinan Ranch, a diked subsided site just south of Pond 3, is proposed for restoration within the next several years. Until that time, the Napa Salt Marsh Restoration must not scour or put at risk the stability of the Cullinan Ranch levees. The hydrodynamic and sediment budget impacts of the Cullinan Ranch restoration must be considered in the Napa Salt Marsh Restoration project planning.

Other adjacent subsided sites (for example, Skaggs Island) which may be restored within the next 50 years, or may be subject to unplanned breaching, could affect evolution of the Napa River Salt Marsh. We presume such events can be addressed via adaptive management.

## 4. PRELIMINARY DESIGN OF THE HABITAT RESTORATION OPTIONS

Prior to development of the preliminary restoration design, certain parameters had already been established by the project sponsors. The project sponsors defined the project goals (see Section 2) and generally agreed upon the basic framework of the habitat restoration options, identifying general habitat type – tidal marsh or managed pond – by pond for each of the restoration options.

PWA assisted with development of the detailed tidal wetland restoration design. A more detailed design was required for the Feasibility Study and EIR/S to communicate the design, provide a basis for cost estimates, support benefit to cost evaluations, and assess environmental impacts.

The following sections discuss long-term habitat types by pond (Section 4.1), the preliminary tidal restoration design (Section 4.2), the design approach (Section 4.3), design criteria for tidal wetland restoration (Section 4.4), restoration design features (Section 4.5), construction methods and sequencing (Section 4.6), and monitoring and adaptive management (Section 4.7).

### 4.1 TIDAL HABITAT GOALS BY OPTION AND BY POND

The project team specified long-term habitat goals by pond to define four Habitat Restoration Options (Table 1). All the options provide for a combination of tidal wetland and managed ponds, but they vary in the relative extents of these habitat types. The distribution of target habitat types by option are shown in Figures 6 through 9. Option 1 provides a mixture of tidal marsh and managed pond habitat. Option 2 emphasizes creation of tidal marsh habitat. Option 3 emphasizes creation of managed pond habitat. Option 4 is the same as Option 1 except that it includes additional berms and fill intended to facilitate and accelerate establishment of tidal marsh inside the ponds. Note that the habitat goals refer to tidal marsh as desired habitat, although the design criteria allow for a mixture of tidal marsh and unvegetated tidal mudflat with the practical limitations of the project (Section 4.4).

In Habitat Restoration Options 1 and 4, Ponds 6 and 6A would be managed as ponds in the short-term. In the medium-term they would be adaptively managed and could be maintained as managed ponds or restored to tidal habitat. This adaptive management decision would be made within 10-20 years and would consider the success of tidal marsh development in Ponds 3, 4, and 5, the availability of other shorebird and waterfowl habitat in the region, and the availability of funds for continued operations and maintenance of the managed ponds. For Habitat Restoration Option 2, a berm would be constructed across Pond 2 to separate the tidal and managed pond areas.

In all options, Pond 3 would be breached first, followed by Ponds 4 and 5 (Pond 4 only for Option 3) within five years. Pond 3 is breached first because it can be desalinated fairly quickly, and it is expected to develop marshplain habitat quickly since it is the least subsided of the ponds (aside from Pond 2A which has already been breached). Pond 3 is also close to the tidal sediment supply and is expected to sediment in more quickly. For Option 2, Ponds 6, 6A, and the eastern half of Pond 2 would be breached

after significant habitat had developed in Ponds 3, 4, and 5. For Options 1 and 4, the decision regarding whether or not to breach Ponds 6 and 6A would be made within 20 years of breaching Pond 3. Option 4 has the same habitat types and phasing as Option 1, but includes design features intended to facilitate creation of tidal marsh habitat more quickly.

## 4.2 PRELIMINARY DESIGN

Preliminary designs for each of the four Habitat Restoration Options are shown schematically on Figures 10 through 13 and described below. Each option includes several common elements – design features to benefit habitat, phased breaching of ponds, adaptive management – and was formulated with consideration of site opportunities and constraints, construction costs, expected habitat evolution, and feasibility.

The design features are intended to improve habitat value by promoting marsh vegetation establishment, habitat connectivity, and development of tidal channels. They include:

- *Levee breaches* to reintroduces tidal flow to the ponds. A breach is an excavation through an earth levee.
- A limited number of *pilot channels* as needed. A pilot channel is an excavated channel through fringing marsh which connects a breach to tidal waters.
- *Starter channels* inside the ponds to provide immediate new channel habitat and improve drainage.
- *Berms* alongside the starter channels to create habitat diversity and provide wave sheltering.
- *Ditch blocks* in the borrow ditches to encourage the re-establishment of natural antecedent channels within the ponds.
- *Lowering sections of levee* to create marsh habitat and wildlife corridors.
- Placing limited amounts of *fill* to accelerate marsh vegetation colonization and compensate for temporary loss of channel fringing marsh habitat.

Figure 14 provides a schematic of the starter channel and berm configuration. Use of the design features in each option was based on detailed design criteria described in Section 4.5.

The habitat mix and habitat evolution associated with each option is presented in Table 2 and plotted in Figures 15 and 16. Figure 17 compares habitat evolution by alternative. The habitat evolution analysis is resented in detail in Appendix C.

### 4.2.1 Habitat Restoration Option 1: Mix of Ponds and Tidal Marsh

The design for Habitat Restoration Option 1 is shown in Figure 10. This option would create 2,900 acres of new tidal wetland and 3,550 acres of managed ponds. Design features include 23 breaches, 22 ditch blocks, 27,500 feet of starter channels and berms, and 22,200 feet of levee lowering, creating a total of 30 acres that are expected to colonize rapidly with marsh vegetation (Table 3). The salinity reduction breaches between Ponds 4 and 5 would be left in place for the tidal restoration.

**Habitat Evolution.** Figures 18, 19, and 20 show expected site evolution at Years 5, 50, and long term, respectively. These habitat schematics use the results of the habitat evolution assessment (Appendix C). Pond 3 is expected to support marsh vegetation in selected areas by Year 5, then broadly across the pond by Year 50 and in the long term. Ponds 4 and 5 are largely intertidal mudflat in Year 5, with small patches of vegetated marsh. By Year 50, the relative area of vegetated marsh increases, but intertidal mudflat remains the predominant habitat type. Long term, these ponds are expected to support a mosaic of vegetated marshplain, channels, and mudflat. The lower grade elevations in Ponds 4 and 5 increase the potential for hindered sedimentation and may limit the eventual extent of vegetated marsh habitat. However, localized areas of these ponds are already high enough under existing conditions to support vegetation even with no additional sedimentation.

Breaches to the All American Canal (located west of Pond 2A) will reestablish tidal wetland within the canal.

South Slough, China Slough, Devil's Slough, and Dutchman Slough (after Cullinan Ranch is breached) are expected to scour in response to the increased tidal prism. Some scour is expected also along the Napa River on the northeast tip of Pond 3 and on the east side of the river across from South Slough (Appendix C). The channels are expected to enlarge initially, then partially fill back in as the ponds sediment in and tidal prism decreases.

**Phasing.** As described previously, Pond 3 would be breached first, followed by Ponds 4 and 5 within approximately five years. Pond 3 is breached first because it can be desalinated fairly quickly, and it is expected to develop marshplain habitat more quickly than the other ponds. The decision regarding whether or not to breach Ponds 6 and 6A would be made within 20 years of breaching Pond 3.

Based on findings from the hydraulic modeling, Pond 3 would be breached first to the Napa River and South Slough, then breached to Dutchman Slough only after Cullinan Ranch is restored. Delaying breaching to Dutchman Slough will reduce scour and the risk of an inadvertent breach at Cullinan Ranch prior to planned breaching for restoration (see Appendix A). If Cullinan Ranch does not appear to be close to restoration before the final design of Pond 3 occurs, the two Pond 3 starter channels that connect to breaches along Dutchman Slough may need to be relocated to South Slough. Drainage to the southern part of Pond 3 would be suboptimal until Pond 3 is breached to Dutchman Slough. Some reduced drainage is acceptable in the short-term, but would not be desirable as a longer-term condition. The advantage of the preferred starter channel locations is that they correspond with the alignments of the largest historic channels, and the adjacent berms are better located to provide wave sheltering benefits near the southern side of the pond.

**Adaptive Management.** The pond-by-pond restoration phasing is a type of adaptive management. Any need for design modifications recognized during the earlier phases can be applied to the later phases. The use of starter channels will also be managed adaptively for potential cost savings. The design approach will be to use starter channels experimentally in parts of Pond 3, assess their benefits during the initial period after Pond 3 is breached, and use the results of this assessment to adapt the designs for Ponds 4 and

5. Depending on the Pond 3 results, starter channels could be removed or reduced in extent in the Ponds 4 and 5 designs. Post-restoration monitoring would be used to assess the contribution of starter channels to habitat development. Rates of channel formation in Pond 3 will be compared for areas with and without starter channels.

#### 4.2.2 Habitat Restoration Option 2: Tidal Marsh Emphasis

The design for Habitat Restoration Option 2 is shown in Figure 11. This Option would create 4,370 acres of new tidal wetland and 2,080 acres of managed ponds. Design features include 31 breaches, 26 ditch blocks, 40,600 feet of starter channels and berms, and 34,600 feet of levee lowering, creating a total of 46 acres that are expected to colonize rapidly with marsh vegetation (Table 3). A levee would be constructed across Pond 2 to separate the managed and tidal halves of the pond. Interior breaches, already constructed for salinity reduction, are included between Ponds 6 and 6A to re-establish the flow path of a large historic channel.

Site evolution is expected to be similar to Option 1, but with additional habitat created in Ponds 2 East, 6, and 6A. The evolution of Ponds 6 and 6A is expected to be similar to, but probably faster than Ponds 4 and 5, since Ponds 6 and 6A are less subsided (Figure 4). The western parts of both ponds and the southern part of Pond 6 are the least subsided areas and are expected to colonize more rapidly than other areas within the ponds. Pond 2 East is deeply subsided and is expected to support only a minimal amount of marsh in Years 5 and 50. Slough erosion will be similar to Option 1, but will extend further upstream adjacent to Ponds 6 and 6A. Some, probably minor, additional erosion may occur in the downstream reaches of the sloughs that are affected in Option 1.

Phasing is as in Option 1, but with an additional later phase in which Ponds 2 east, 6, and 6A are restored. In addition to the adaptive management measures included in Option 1, starter channel and berm construction in Ponds 2 East, 6, and 6A will be managed adaptively based on the experience with these features in Ponds 3, 4, and 5, taking into account the possibility of a gypsum layer in Ponds 6 and 6A.

#### 4.2.3 Habitat Restoration Option 3: Pond Emphasis

The design for Habitat Restoration Option 3 is shown in Figure 12. This Option would create 2,160 acres of new tidal wetland and 4,290 acres of managed ponds. Design features include 19 breaches, 16 ditch blocks, 19,600 feet of starter channels and berms, and 14,600 feet of levee lowering, creating a total of 20 acres that are expected to colonize rapidly with marsh vegetation (Table 3). The salinity reduction breaches between Ponds 4 and 5 would be filled to create a continuous levee between these ponds.

Site evolution is expected to be similar to Option 1, but without Pond 5 restored to tidal habitat. Slough erosion will be similar to Option 1, but will not be as extensive along parts of China and Devil's Slough, particularly near Pond 5. Phasing and adaptive management are the same as Option 1, but without Pond 5 restored.

#### 4.2.4 Habitat Restoration Option 4: Accelerated Restoration

The design for Habitat Restoration Option 4 is shown in Figure 13. This Option is similar to Option 1, but includes additional starter channels, berms, and fill to promote more rapid and extensive marsh evolution. Option 4 would create 2,900 acres of new tidal wetland and 3,550 acres of managed ponds. Design features include 23 breaches, 22 ditch blocks, 55,300 feet of starter channels and berms, 22,200 feet of levee lowering, and up to 100 acres of fill, creating a total of up to 136 acres that are expected to colonize rapidly with marsh vegetation (Table 3).

The fill would be placed to offset temporary marsh losses during the initial period when marsh loss from channel erosion is expected to outpace new marsh formation in the ponds. According to habitat evolution estimates (Appendix C), this temporary loss is approximately 70 acres. Therefore 70 acres of fill may be sufficient. The fill location shown on Figure 13 is for example only. Per the design criteria, fill would be placed where there is low antecedent channel density and easy access to the Napa River.

Because of the additional conveyance of the starter channels, wave sheltering of the berms, and fill, site evolution is expected to be more rapid in Option 4 than in Option 1 (quantified in Appendix C). Slough erosion also is expected to occur more rapidly and be slightly greater in extent because of the improved drainage in the ponds and greater tidal prism mobilized by the starter channels. Breach phasing and adaptive management are as in Option 1.

### 4.3 DESIGN APPROACH

The design process was a collaborative effort between the project team and PWA, with valuable input provided by the NSMR Group, the RTAG, and the staff of Jones & Stokes and Brown & Caldwell.

#### 4.3.1 Design Approach

The tidal wetland design approach is to create an initial site template that will guide the action of natural physical and vegetative processes after breaching to form a self-sustaining tidal wetland system. Our approach is to rely primarily on natural sedimentation to raise site subsided elevations, tidal scour to re-establish channels, and natural vegetative colonization to establish marsh vegetation. Direct interventions such as grading and filling are minimized, as possible, in the design. However, any target habitat features, such as extensive tidal channel networks, that may not evolve on their own are included in the design template, or given enough of a “jump start” in the design that they will likely develop. Important to the design approach is an understanding of how tidal habitats will likely evolve over time. This is described below in this section.

Design features – breaches, ditch blocks, starter channels, berms, levee lowering, and others – comprise the components of the site template. They address site opportunities and constraints to meet the habitat goals, in consideration of expected habitat evolution. Habitat restoration design features are described in Section 4.5.

#### 4.3.2 Tidal Wetland Habitats

Tidal wetland habitat types are described in the EIR/EIS (Chapter 2.5.4.1) and summarized here. Tidal wetlands are areas subject to tidal inundation and consist of tidal marsh (vegetated wetland), intertidal mudflat, and subtidal mudflat (see Figure 2-13 in the EIR/EIS). There are three general types of vegetated tidal marsh – low marsh, mid marsh, and upper (high) marsh – roughly corresponding to varying tidal elevations. In the Napa River marshes, low marsh is characterized by *Spartina foliosa* (California cordgrass), *Scirpus maritimus* (bulrush), and sometimes *Typha spp.* (cattail). Low marsh typically occurs along the edges of channels and gently sloping mudflats. Mid marsh, or the vegetated marshplain, is characterized by *Salicornia virginica* (pickleweed). Upper marsh occurs at the marshplain-upland transition and is vegetated with a variety of marsh species.

#### 4.3.3 Conceptual Model of Restored Tidal Marsh Evolution

While habitat within the managed non-tidal ponds will remain relatively constant over time, the restored tidal ponds will evolve in response to natural physical and biological processes. Primarily, these processes include:

- vegetation establishment at preferred tidal elevations specific to marsh plant species and
- accretion by mineral sediment deposition, raising sub-tidal and low inter-tidal areas to elevations at which vegetation colonization can occur.

Once tidal action is restored to a subsided site through a deliberate or accidental levee breach, physical processes are set in motion that dictate how the site will evolve.

These processes for inorganic sediment-dominated marshes such as the Napa marsh system and others fringing San Francisco Bay have been described in conceptual models of youthful salt marsh development. A discussion of these models is provided in Allen (2000), which is summarized here in simplified form and shown schematically in Figure 21. Flood tides carry in suspended estuarine sediments that deposit in the slack waters of the flooded site. Ebb tidal currents are insufficient to resuspend deposited muds and silts, except in the locations of nascent tidal channels. As sediment accumulates, large areas of intertidal mudflats form. As they rise in elevation, the period of inundation decreases and rate of sedimentation declines. Once the mudflats reach a high enough elevation relative to the tidal frame, pioneer vegetative colonization can occur. Colonization becomes progressively quicker through lateral expansion once initial colonizing plants have established. Figure 22 illustrates the conceptual model of how the elevation of a subsided site is anticipated to evolve in response to estuarine sedimentation processes, from subtidal, to intertidal mudflat, to initial mudflat colonization by salt-tolerant marsh plants to ultimately form a fully mature vegetated marshplain. For this representation, episodic events such as large storms and floods are smoothed out and sea level rise is excluded. Any long-term sea level rise would result in increased ground elevations over time. Wind wave processes are implicitly included in terms of re-arranging deposited sediment throughout the site.

Once mudflat colonization occurs, a vegetated marshplain forms through lateral expansion of rhizomes from each established plant on the mudflat, and from plants along the site perimeter. The presence of vegetation contributes to vertical accretion through sediment trapping and organic accumulation (Eisma

and Dijkema, 1997). As the marshplain rises within the tidal frame, estuarine sediment accretion slows exponentially until a marshplain forms at an elevation below the highest spring tides (Allen, 1990), or in the case of San Francisco Bay marshes within a few decimeters of MHHW (Atwater et al. 1979).

This conceptual model presumes high rates of sedimentation relative to sea level rise. In actuality, the process of marsh generation described here can be stalled or even reversed under certain conditions. Low suspended sediment supply and/or high wind wave activity can slow sediment deposition and vegetation establishment, leading to development of mudflats in lieu of vegetated marsh. These limiting factors are considered in the NRSMR habitat evolution estimates (Appendix C).

#### 4.4 GENERAL DESIGN CRITERIA

General criteria to guide the overall design were developed with the project team, with input from the RTAG. The general design criteria used to balance competing objectives are:

1. Establish site conditions conducive to natural evolution of tidal marsh and a diversity of tidal wetland habitats.
2. Create and maintain tidal wetland habitats that sustain viable wildlife populations, particularly for Bay Area special status species. Maintain habitat connectivity and carrying capacity.
3. Design the restoration to minimize costs in achieving the project goals.

Applying the design criteria to the Napa River Salt Pond Restoration site requires balancing competing goals. For example, creating conditions for natural evolution of tidal marsh (a target habitat identified in the project goals) could be costly and require extensive construction in some of the ponds. Maximizing the certainty that tidal marsh will evolve in a relatively subsided pond (e.g., Ponds 4 and 5) would involve creation of sheltered conditions for sedimentation (i.e., a large number and extent of berms) and possibly fill placement. The tidal wetland design (Section 4.2) represents a balance between using berms and fill to promote marsh colonization and maintaining construction costs at a practical level. This balance was decided upon by the project sponsors with input from the RTAG and PWA. In addition, the project sponsors and biologists on the RTAG acknowledged the biological value of a mosaic of tidal habitats, not just vegetated tidal marshplain with channels, if the site were ultimately to evolve toward a mixed mudflat and marsh habitat endpoint.

#### 4.5 DESIGN FEATURES

This section provides descriptions of the design features, their purposes, how they would be constructed, and detailed design criteria used to guide the incorporation of these features into the design. PWA developed an initial set of design criteria then met with the project team and RTAG in a “design charette” in April 2002 to refine these criteria. Approximate dimensions of the design features, key design elevations, and area of mid marsh habitat created, are presented in Table 4.

#### 4.5.1 Breaches

A breach is an excavation through an earth levee through which tidal exchange is provided to and from the pond. Interior breaches through interior levees allow continuity of tidal flow between two ponds, such as between Ponds 6 and 6A.

Design criteria:

- Size the breaches to provide full tidal exchange between the sloughs and the ponds.
- Target tributary drainage areas vary between approximately 100 to 200 acres or less for each breach.
- Locate breaches at or near historic channel locations, as possible.
  - ▶ Location opportunities: at historic channel locations, near the Napa River to minimize the potential for tidal muting, near sources of tidal and fluvial sediment (i.e., near the Napa River), where water control structures are to be removed (we will also use the habitat restoration design to guide the locations of new water control structures for salinity reduction as possible).
  - ▶ Location constraints to avoid: near power towers and other infrastructure, near wide fringe marsh where pilot channels would be required (avoid as possible), where breaches would cause fragmentation of fringe marsh, across from existing levees to be maintained where these levees would be susceptible to damage by erosion.
- Phase by pond and also by individual breach to facilitate success.

The opportunity for locating breaching Pond 3 along the Napa River was limited because there is only one major antecedent channel in this area (which was only a small channel historically) and there is a wide band of higher elevation land within Pond 3 along Napa River. This high land within the pond is marsh that has been leveed only more recently, so has subsided less. Since the siphon between Pond 3 and the All American Canal will likely be decommissioned by filling it with concrete rather than excavating it, this was not treated as a breach location opportunity.

#### 4.5.2 Pilot Channels

A pilot channel is an excavated channel extending from a breach through existing vegetated marsh to tidal waters. The pilot channel is intended to facilitate tidal exchange through a breach by providing a small initial flow path and removing erosion-resistant marsh vegetation so the channel can gradually enlarge through tidal scour. To minimize impacts to existing marsh and minimize construction costs, pilot channels are generally narrower and shallower than breach excavations. Given the difficulties and costs associated with this construction, the design reduces the number and length of pilot channels by locating breaches away from wide fringing marshes as possible.

#### 4.5.3 Starter Channels

A starter channel is an excavated channel extending from a breach into a pond (Figure 14). Starter channels are generally located to correspond with historic channel paths. They benefit habitat restoration

by providing habitat for fish soon after construction, and by facilitating more rapid channel development overall. They may increase the long-term density of tidal channels by allowing the most upstream channels to scour prior to the establishment of erosion-resistant vegetation. These channels may ultimately become habitat for rails and other wildlife, resulting in long-term habitat benefits. The starter channels also improve site drainage, which enhances rates of sedimentation and vegetation establishment.

Design criteria:

- Locate starter channels within the historic channel alignments. In selected instances, it may be desirable to construct channels in non-historic locations to provide additional drainage. This is the case with the starter channel at the south breach in Pond 4, which is designed to align with an advantageous breach location and does not correspond with an historic channel location.
- Limit the lengths of starter channels to those that can be constructed in a cost effective manner.
- Cross-section dimensions consistent with long-term channel geometry, or smaller to reduce costs
- Locate starter channels consistent with berm locations (see berm design criteria below).
- Use starter channels experimentally and adaptively manage their use to reduce costs (Section 4.2.1).

#### 4.5.4 Berms

A berm is a curvilinear earth fill located alongside a starter channel within a pond (Figure 14). Berms directly facilitate rapid development of a diversity of marsh habitat by providing ground elevations conducive to vegetation establishment. Berms also facilitate marsh development by serving as dissipaters of wave energy, creating more sheltered conditions conducive to sedimentation and vegetation colonization. To the extent practicable, berms may be used to limit fetches and reduce wave action within the site. Excavated earth from the starter channels serves as the source of fill for berm construction, with the amount of earth excavated equaling the amount used in berm construction. The berm crest elevation would vary around MHHW. The intent is an irregular, wide, low height mound with flat slopes. Berms would be constructed along one or both sides of the channel and would be discontinuous to avoid covering the junctions with smaller side channels.

#### 4.5.5 Ditch Blocks

A ditch block is an earth fill that crosses an existing borrow ditch to inhibit flow. Borrow ditches are human-constructed channels adjacent to levees which tend to be straighter and offer less habitat complexity than natural channels. All of the ponds have borrow ditches on the inboard side of the perimeter levees. The purpose of ditch blocks is to inhibit existing borrow ditches from capturing the tidal supply and impeding re-establishment of the historic channels. Ditch blocks would be located to facilitate evolution of a more natural channel pattern (planform location, density and sinuosity) generally consistent with the historic channel pattern. Since borrow ditches will provide much of the channel habitat immediately after breaching, ditch blocks will be located to maintain this initial habitat. Only one block will be used between each pair of breaches, ensuring that the borrow ditch remains connected to a tidal source on each side of the block. This approach also avoids creating undrained sections of ditch between

two blocks, which could trap fish between high tides. The adjacent section of levee would be lowered to provide earth fill and access for construction of the ditch blocks.

#### 4.5.6 Levee Lowering

Levee lowering consists of excavating the upper portion of an existing levee to elevations consistent with vegetated marshplain, around MHHW. Material generated from levee lowering will be moved into the adjacent borrow ditch to create additional marsh habitat. Only part of the borrow ditch cross-section (approximately 16 ft) will be filled and channel conveyance will be maintained.

Levee lowering over key sections of levee will provide habitat corridors and marsh continuity along the slough channels and between the pond interior and sloughs. Since levees can provide access and habitat for predators that compromise the ecologic objectives of restoration, levee lowering also reduces these negative effects. Levee lowering as referred to here is in addition to that accompanying the construction of ditch blocks.

The exact design criteria for providing corridors and connectivity have not been determined and will be developed with additional biological input from the resource agencies, in particular the USFWS. The following preliminary criteria were developed according to guidance provided by the project team and RTAG members in the design charette.<sup>1</sup> The final design criteria may result in different levee lowering locations, but the overall extent of levee lowering is expected to be similar.

- Lower levees where post-project flows are expected to result in erosion of existing fringe marshes larger than a threshold size.
- Threshold existing marsh size is defined as wider than approximately 100 feet and longer than approximately 2000 feet.
- Hydraulic modeling results were used to identify areas susceptible to channel and marsh erosion along the sloughs and along the Napa River at the northeast tip of Pond 3.
- Levees will not be lowered where existing fringe marsh is directly connected to a large patch of fringe marsh that is expected to persist after breaching of the ponds. Most fringe marsh along the Napa River is expected to persist, as well as several pockets of marsh along the slough.
- Levees will also be lowered along small lengths near the breaches, to provide a habitat corridor along the new breach channels.
- Avoid lowering levees that provide wave sheltering to other levees that will be maintained.

The total extent of levee lowering must be compatible with an acceptable level of temporary construction impacts. Levee lowering construction must be timed to avoid inadvertent breaching.

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<sup>1</sup> Initial input from USFWS staff (P. Baye, pers. comm.) suggests that levee lowering criteria may be revised to prioritize areas near high value fringe marsh habitat, such as the south end of Pond 3, northeast of the junction of Ponds 4 and 5, and along Napa Slough.

#### 4.5.7 Fill Placement

This design feature, used only in Option 4, consists of placing earthen fill (sediment) on the subsided marshplain with the purpose of accelerating evolution to a vegetated marsh. Fill placement would address the concern raised by some stakeholders that erosion of fringing marsh along the sloughs channels would occur more rapidly than development of new marsh within the ponds, resulting in a temporary loss of marsh habitat. Fill would be placed into either the southern portion of Pond 4, the area where Ponds 4 and 5 connect, the northern portion of Pond 5, or a similar location with low historic channel density and easy access to the Napa River. Sediment would be placed no higher than one foot below MHHW elevation, to facilitate channel development on the new marsh. Sediment would be generated by dredging sloughs onsite or would be imported. Fill can be placed by bucket or hydraulic means. Any sediment used in this fill would be wetland cover quality.

#### 4.5.8 Design Feature Considered and Rejected

Deepening the slough channels via dredging was considered earlier in the project design in order to increase conveyance, but has been rejected based on the results of the hydraulic modeling which show that it is not necessary for project success (Appendix A). This measure was initially considered as a means of ensuring that any capacity limitations in the sloughs would not significantly restrict tidal exchange and limit marsh establishment. The existing sloughs have silted in considerably since the 1850s. Enlarging them as part of the restoration would have anticipated the natural process of channel scour. Although dredging for the purposes of increasing conveyance has been rejected, the sloughs may be used as a source of fill for construction of other design features (see above).

### 4.6 CONSTRUCTION METHODS AND SEQUENCING

Proposed construction methods were developed collaboratively by PWA, Brown & Caldwell, and the USACE, with input from CDFG. PWA provided conceptual descriptions of restoration elements and assisted Brown & Caldwell with development of preliminary engineer's estimates of construction quantities and costs. The purpose of the work was to develop an approximate estimate of construction costs (about 10% complete level) and confirm construction feasibility. The effort also helped identify elements that could have major cost implications, leading to revisions and targeting of future design efforts. The proposed construction methods used to estimate costs and the proposed sequencing are discussed below. Actual construction methods and sequencing may vary based on a number of factors, including the selected construction contractor's expertise and equipment. Additional construction details by restoration element are provided in the Feasibility Study.

Breaches and pilot channels would be created using explosives, as was done by CDFG at Pond 2A. Starter channels and berms would most likely be constructed using barge-based equipment, such as a barge-mounted hydraulic suction dredge or clamshell excavator. Sediments excavated from the starter channels would be deposited to create the berms. Drawdown of pond water levels would probably not be required. Dynamic excavation (using explosives) and use of land-based equipment were also considered. Dynamic excavation was rejected because it would be disruptive to wildlife and humans, and because the

excavated mud could not be used in berm construction. Use of land-based equipment, although less expensive, is probably not feasible given the low soil strengths and risk for equipment to sink in the mud. Also, there are potential problems associated with draining the ponds, as would be required for land-based access. Ditch blocks and levee lowering would be constructed with land-based equipment delivered by barge. Travel between construction locations would occur along the levee, excluding any levee sections separated by breaches. Area fill would be placed by bucket or hydraulic means. Sediment would be generated by dredging sloughs onsite or would be imported.

In general, design elements in the pond interiors would be constructed prior to breaching. Because levee lowering would be time intensive, this would need to occur during construction of the interior design elements. At high tide, equipment would be stored on high levee crests. To avoid inadvertent breaching in locations of levee lowering, part of the levee cross section can be left slightly higher than the highest tides, then later removed relatively quickly during a neap tide series prior to breaching. Levee lowering can continue after breaching, but will require barge transport across the breaches.

#### 4.7 MONITORING AND ADAPTIVE MANAGEMENT

The project design has been formulated to rely upon adaptive management based on monitoring of actual conditions as the project site and environs evolve. The project is phased to facilitate maximum benefit and minimize cost of adaptive management activities. The Adaptive Management and Monitoring and Monitoring Plans are key elements of future design.

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## 6. REFERENCES

- Allen, J.R.L., 1990. Morphodynamics of Holocene salt marshes: a review sketch from the Atlantic and Southern North Sea coasts of Europe. *Quaternary Science Reviews*, 19, pp. 115-1231.
- Atwater, B.F., S.G. Conard, J.N. Dowden, C.W. Hedel, R.L. MacDonald and W. Savage, 1979. "History, Landforms and Vegetation of the Estuary's Tidal Marshes" in *San Francisco Bay: the Urbanised Estuary*, TJ Conomos, AE Leviton and M Berson (eds), Pac. Div. Amer. Assn. Adv. Sci.
- Eisma, D. and K.S. Dijkema., 1997. The influence of salt marsh vegetation on sedimentation. In: (D. Eisma, ed.) *Intertidal Deposits*. CRC Press, Boca Raton, FL, pp. 403-414.
- Jones and Stokes (JSA), 2002. Napa River Salt Marsh Restoration Project Environmental Impact Report/Environmental Impact Statement (EIR/EIS).
- Goals Project. 1999. Baylands Ecosystem Habitat Goals. A report of habitat recommendations prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. U.S. Environmental Protection Agency, San Francisco, Calif./S.F. Bay Regional Water Quality Control Board, Oakland, Calif.
- Philip Williams & Associates (PWA), 2001a. Napa-Sonoma Marsh Restoration Feasibility Study, Napa Siphon Field Data Collection. Prepared for the U.S. Army Corps of Engineers, San Francisco District, CA. Project #1411-02. March 2001.
- Philip Williams & Associates (PWA), 2001b. Napa-Sonoma Marsh Restoration Feasibility Study, Intermediate Scoping (Phase 1B) for Phase 2. Prepared for the U.S. Army Corps of Engineers, San Francisco District, CA. Project #1411 Task 12. July 2001.
- Philip Williams & Associates (PWA), 2002a. Napa Sonoma Marsh Restoration Feasibility Study – Phase 1 : Hydrodynamic Modeling Analysis of Existing Conditions. Prepared for the U.S. Army Corps of Engineers, San Francisco District, CA. Report # 1174-8. March 13, 2002.
- Philip Williams & Associates, (PWA), 2002b. Napa Sonoma Marsh Restoration Feasibility Study - Phase 2 Stage 1 Preliminary Salinity Reduction , Habitat Evolution, and Sediment Budget. Prepared for the California Coastal Conservancy. Project #1546/45. June 2002.
- Philip Williams & Associates (PWA), 2002c. Cooley Landing / Pond 2A Channel Evolution Comparison Study. Prepared for the U.S. Fish and Wildlife Service. Project # 1517. March 2002.
- Philip Williams & Associates (PWA), 2002d. Cooley Landing Salt Pond Restoration Baseline and Year 1 Monitoring Report. Report # 1556. July 2002.

San Francisco Estuary Institute (SFEI), 1998. Spatial Analysis of the Baylands Ecosystem (Draft). Prepared for the Resource Managers Group and Focus Teams, Bay Area Wetlands Ecosystem Goals Project. January 20.

Towill, Inc., 2001. Napa Salt Marsh Restoration Project, Topographic and Hydrographic Surveys; Ground Control and Hydrographic Survey Report. Prepared for the U.S. Army Corps of Engineers, San Francisco District, CA.

Warner, J.C., 2000. Barotropic and Baroclinic Convergence Zones in Tidal Channels. Ph.D. Dissertation, University of California at Davis.

Williams, P.B., M. Orr, and N. Garrity, 2002. "Hydraulic Geometry : A Geomorphic Design Tool for Tidal Marsh Channel Evolution in Wetland Restoration Projects", Restoration Ecology, September 2002, 10:3, pp. 577-590.

U.S. Army Corps of Engineers, San Francisco District (USACE), 2002. Napa River Salt Marsh Restoration Draft Feasibility Study. United States Corps of Engineers, San Francisco District.

## Tables

**Table 1. Ponds of Each Habitat Type by Habitat Restoration Option**

<b>Habitat Restoration Option</b>	<b>Habitat Type</b>		
	<b>Tidal Wetland</b>	<b>Managed Pond</b>	<b>Adaptively Managed</b>
Option 1: Mixture of Tidal Marsh and Managed Ponds	Ponds 2A*, 3, 4, and 5	Ponds 1, 1A, 2, 2A, 7, 7A, and 8	Ponds 6 and 6A
Option 2: Tidal Marsh Emphasis	Ponds 2A*, 3, 4, 5, 6, 6A, and the eastern half of Pond 2	Ponds 1, 1A, 2A, 7, 7A, 8, and the western half of Pond 2	None
Option 3: Pond Emphasis	Ponds 2A*, 3 and 4	Ponds 1, 1A, 2, 2A, 5, 6, 6A, 7, 7A, and 8	None
Option 4: Accelerated Restoration	Ponds 2A*, 3, 4, and 5	Ponds 1, 1A, 2, 2A, 7, 7A, and 8	Ponds 6 and 6A

\* Pond 2A was breached by CDFG in 1995 and is already tidal habitat.

**Table 2. Habitat Mix Associated with All Options**

Insert Excel table: P:\Projects\1591\_NSMR\_P2S2\Task10\_report\ Tabs&Figs\_ng.xls \ Revised Table 2

**Table 3. Number and Length of Design Elements and Mid Marsh Habitat Created by Option**

	Option 1	Option 2	Option 3	Option 4
<b>Number and length of design elements</b>				
Breaches (number)	23	31	19	23
Ditch blocks (number)	22	26	16	22 <sup>a</sup>
Lowered levees <sup>b</sup> (feet)	22,200	34,600	14,600	22,200
Berms (feet)	27,500	40,600	19,600	55,300
Starter channels (feet)	27,500	40,600	19,600	55,300
<b>Mid marsh area created by design feature (acres)</b>				
Ditch blocks	3	3	2	3
Lowered levees <sup>c</sup>	21	34	13	21
Berms	6	9	4	13
Area fill	-	-	-	100
Total	30	46	20	136

a- Fewer ditch blocks may be needed, depending on the location of the fill placement.

b- Includes 330 ft for each ditch block.

c- Includes area of partial borrow ditch fill, except when that fill is a ditch block.

**Table 4. Approximate Dimensions of Design Elements**

<b>Design element</b>	<b>Top width (ft)</b>	<b>Key Elevations</b>	<b>Typical Side Slope<sup>a</sup> (H:V)</b>	<b>Length (ft)</b>	<b>Potential mid marsh area created</b>
Breach	Approx. 100 <sup>b</sup>	Invert 3 to 5 ft below MLLW	5:1	NA	NA
Pilot Channel	~50	Minimum invert at least several feet below the marshplain	5:1	Varies	NA
Starter channel <sup>c</sup>	50 – 100	Longitudinal slope deepest near the breach (3 to 5 ft below MLLW) and shallower in the pond interior (1 ft above to 1 ft below MLLW)	5:1	Varies by option	NA
Berm <sup>d</sup>	Approx. 10	~MLHW to MHW at crest; no higher than +0.5 ft above MHHW	7:1	Varies by option	0.2 ac / 1000 ft
Ditch block <sup>e</sup>	40	~MHHW at crest	5:1	100	0.12 ac / block
Levee lowered to construct ditch block	30	~MHHW at crest	NA	330	0.23 ac / block
Additional levee lowering for marsh restoration <sup>f</sup>	46	~MHHW at crest	NA	Varies by option	1.1 ac / 1000 ft
Fill placement	NA	~1 ft below MHHW	NA	NA	100 ac assumed, may be less