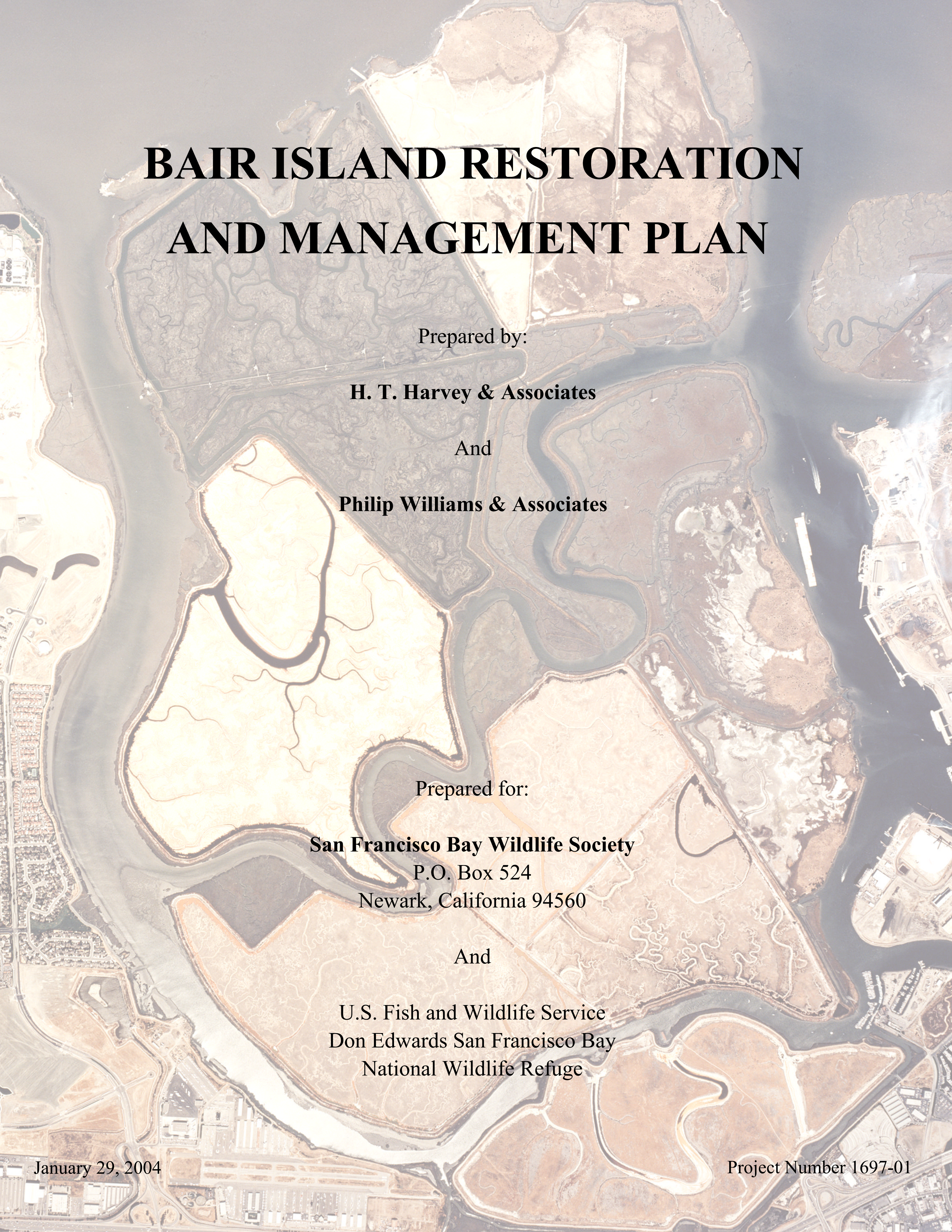
APPENDIX A

Bair Island Restoration and Management Plan



BAIR ISLAND RESTORATION AND MANAGEMENT PLAN

Prepared by:

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Prepared for:

San Francisco Bay Wildlife Society
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And

U.S. Fish and Wildlife Service
Don Edwards San Francisco Bay
National Wildlife Refuge

January 29, 2004 | Project Number 1697-01

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TABLE OF CONTENTS

FIGURES (APPENDIX A)

TABLES:

APPENDICES:

1.0 INTRODUCTION

Bair Island is a former tidal salt marsh that is located adjacent to San Francisco Bay in Redwood City, San Mateo County, California (Figure 1). Bair Island has been the target of numerous development proposals through the years, all of which were rejected. The California Department of Fish and Game (CDFG) and the Don Edwards San Francisco Bay National Wildlife Refuge (Refuge) both acquired portions of Bair Island over time. In 1997, the Peninsula Open Space Trust (POST) purchased the remaining portions of Bair Island and turned over their interests in the property to these agencies. The San Carlos Airport also retains a portion of Inner Bair Island as a safety zone. In addition, two easements exist on Bair Island, one for the PG&E towers and transmission lines that run throughout the Bair Island complex, the other for the South Bayside System Authority (SBSA) force main that is located underneath most of the southern levee on Inner Bair.

Historically Bair Island was part of a large complex of tidal marshes and mudflats within the drainage of Redwood Creek and Steinberger Slough (Appendix E). Bair Island was diked in the late 1800's and early 1900's for agricultural practices including cattle grazing. Bair Island was converted to salt evaporation ponds by Leslie Salt Company starting in 1946, and remained in production until 1965. The lands were drained and eventually sold to a series of real estate development companies. An EIR was prepared in 1981 for the South Shores Concept Plan that proposed development of Inner and part of Middle Bair Island (EIP 1981). A local referendum in Redwood City finally halted development plans for Bair Island. POST purchased Bair Island in 1997.

This site is a large, restorable complex of former salt evaporators, and has been a major priority for addition to the Refuge since the original boundaries were drawn. The restoration of tidal habitats at Bair Island is ecologically important to South San Francisco Bay. Following restoration, Bair Island will become an integral part of the extensive wetland complex within the Don Edwards San Francisco Bay National Wildlife Refuge (Refuge) and adjacent state and privately owned wetlands.

The goal of the restoration design is to restore tidal marshes on Bair Island, thereby minimizing management needs in the future, and providing salt marsh habitat for endangered species such as the California Clapper Rail (*Rallus longirostris obsoletus*) and salt marsh harvest mouse (*Reithrodontomys raviventris raviventris*). This site, once properly restored, can assist with the preservation and perhaps recovery of both species.

The Bair Island complex is divided into three distinct areas separated by slough channels: Inner, Middle and Outer Bair. Inner Bair Island is connected to the mainland and can be directly accessed via Whipple Avenue. It is separated from Middle Bair by Smith Slough, which in turn is separated from Outer Bair by Corkscrew Slough. This Restoration and Management Plan does not cover those privately-owned portions of Bair Island that are outside of the project boundary (Figure 1).

The conceptual plan that is presented in this report includes an overview of the alternatives analysis, the selection of a preferred restoration alternative and the conceptual design for the preferred alternative. The biological goals and objectives as well as the site opportunities and constraints were used to guide the selection of alternatives. The goals and objectives are committed to the restoration of the natural landscape and structure of Bair Island.

The preferred alternative (Figure 2) would breach the levees on Middle and Outer Bair Islands to allow natural sedimentation processes to restore tidal salt marsh. Additionally, the preferred alternative would use dredged material to raise the elevation of Inner Bair Island as well as protect the San Carlos Airport property and South Bayside System Authority (SBSA) sewer line (Figure 3). Following the placement of dredged material, the levees of Inner Bair Island would be breached to provide tidal action. Modifications to Smith Slough and Corkscrew Slough are included in the restoration design to allow Bair Island to be successfully restored while avoiding the problems of inducing increased siltation in the Redwood Creek shipping channel and increasing tidal currents in Pete's Outer Harbor. Smith Slough would be rerouted to its historic channel alignment, reestablishing the channel meander through Inner Bair. A channel constriction would be constructed in Corkscrew Slough. Expected long-term habitats are shown on Figure 4.

The Bair Island Restoration and Management Plan was prepared by H.T. Harvey & Associates and PWA (Philip Williams & Associates) for the San Francisco Bay Wildlife Society and the U.S. Fish and Wildlife Service Don Edwards San Francisco Bay National Wildlife Refuge. Funding was provided by the San Francisco Bay Wildlife Society, the California Coastal Conservancy, the U.S Fish and Wildlife Service, the California Department of Fish and Game, the Peninsula Open Space Trust, and the California Wildlife Conservation Board. The Plan was developed with the participation and input of the Bair Island Technical Review Team (TRT). The project team wishes to acknowledge the contributions of the TRT, comprising representatives from U.S. Fish and Wildlife Service, Bay Conservation and Development Commission, California Coastal Conservancy, California Department of Fish and Game, National Marine Fisheries Service, Regional Water Quality Control Board, U.S. Geological Survey, U.S. Environmental Protection Agency and U.S. Army Corps of Engineers.

1.1 DEFINITION OF TERMS

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

Borrow Ditch
Channels created adjacent to levees by the process of "borrowing" material to create the levee. They 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.

Cut-off Berm
Earth fill that crosses an existing borrow ditch to inhibit flow.

Fetch (Wind Fetch)
An area of open water over which wind blows to generate waves.

Headcut
An erosion point in a channel that occurs where there is an abrupt drop in the channel bottom elevation in the downstream direction.

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.

NGVD
National Geodetic Vertical Datum. A fixed vertical datum at the mean sea level of 1929. Used in this study for consistency with previous ground surveys. NGVD has been superceded by NAVD88, which came into common use in the San Francisco Bay Area during the course of this study.

SBSA
South Bayside System Authority (owners of sewer line on Inner Bair).

Slough
In general use, a tidal channel. In this project the term may also refer specifically to the major (named) tidal channels between the ponds (e.g., Steinberger Slough, Smith Slough, Corkscrew 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 Frame
The elevation range of the tides.

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

TRT
Bair Island Technical Review Team.

2.0 PROJECT GOALS AND OBJECTIVES

2.1 DEVELOPMENT OF RESTORATION GOALS AND OBJECTIVES

The goals and objectives for the restoration of Bair Island were developed by the San Francisco Bay Wildlife Society (SFBWS) and the U. S. Fish and Wildlife Service (USFWS). These goals and objectives, presented below, are consistent with the policies of the Don Edwards San Francisco Bay National Wildlife Refuge, to which Bair Island now belongs. We assume a 50-year planning horizon, consistent with that used by other San Francisco Bay restoration projects currently in planning.

2.1.1 Goals for the Bair Island Restoration Project

- Restore Bair Island to tidal salt marsh habitat
- Provide habitat for endangered species and other native wildlife
- Enhance the public's appreciation and awareness of the unique resources of Bair Island

2.1.2 Objectives for the Bair Island Restoration Project

- Restore and enhance habitat for the endangered California Clapper Rail and salt marsh harvest mouse
- Create and enhance habitat for the endangered California Least Tern, California sea-blite, and other wetland dependent species, if compatible with restoration for the Clapper Rail and harvest mouse
- Minimize disturbance to sensitive species (e.g., Clapper Rail, harbor seals)
- Provide for control of undesirable species including invasive plants, undesirable predators and mosquitoes
- Enhance the public's awareness of the unique resources at Bair Island by providing opportunities for wildlife-oriented recreation and nature study

2.2 DESCRIPTION OF TARGET HABITATS

The project goals and objectives outline the general target habitats for Bair Island following the completion of site restoration. The target habitat for Bair Island is salt marsh. However, implied within the creation of salt marsh habitat is the creation of interrelated habitats. These interrelated habitats include channels/subtidal zones, tidal mudflats and upland transition zones, all of which are described below.

2.2.1 Tidal Salt Marsh

Tidal salt marsh habitat in San Francisco Bay is located between mean tide level (MTL) and the highest tide. Cordgrass (*Spartina foliosa*) is the dominant plant species in the low marsh located at an elevation between MTL and mean high water (MHW). Pickleweed (*Salicornia virginica*) is the dominant plant species within the middle marsh located at an elevation between MHW and mean higher high water (MHHW). A mix of salt marsh plant species including saltgrass

(*Distichlis spicata*), pickleweed and spearscale (*Atriplex triangularis*) is found in the high marsh located at an elevation between MHHW and the highest tide.

2.2.2 Channels and Subtidal Zone

Channels and subtidal habitat are located at an elevation below mean lower low water (MLLW). Channels are typically imbedded within tidal marshes and vary in width and depth. These areas are entirely unvegetated.

2.2.3 Tidal Mudflats

Tidal mudflats are located between MLLW and MTL and are typically inundated twice daily. These mudflats are unvegetated because of the stresses associated with long periods of inundation and wave energy. Tidal mudflats are typically located adjacent to tidal marshes at the edge of the bay or slough channels.

2.2.4 Upland/Transition Zone

Uplands and the transition zone between upland habitats and the high marsh are located at an elevation above the highest tide. These habitats are typically located on the periphery of tidal salt marshes or occur as levees and are imbedded within the tidal marsh/channel complex. Upland areas adjacent to tidal marshes in San Francisco Bay are typically dominated by herbaceous non-native, salt tolerant plant species.

3.0 SITE DESCRIPTION

3.1 HISTORIC CONDITIONS

3.1.1 Physical

Bair Island is a former tidal salt marsh that has undergone considerable natural and anthropogenic changes. Although existing hydrologic conditions at the site have been substantially modified from historical conditions, some of the existing characteristics are remnants of historic processes and changes, and are best understood within an historic context.

The description of historic conditions at the site is based on a review of existing information, including historic United States Coast and Geodetic Survey (USCGS) maps, United States Geological Survey (USGS) topographic maps, historical aerial photographs, and secondary studies. These studies include: Bair Island Environmental Study (SLC 1977) and Bair Island Ecological Reserve Operations and Maintenance Plan (RTC 1991).

The Natural Landscape. Bair Island was once part of a continuous band of tidal salt marsh wetland fringing the southwest shoreline of southern San Francisco Bay. San Francisco Bay was formed over the past 10,000 years by sea level transgression (Atwater *et al*. 1979). Rising sea levels submerged previously upland valley areas. From the time of initial submergence until large-scale reclamation began approximately 150 years ago, the aerial extent of the Bay's tidal marshes was determined by the interaction of sea level rise, estuarine sedimentation and wind wave erosion.

Initially, the Bay was rapidly submerged by sea levels rising at approximately 10 times the current rate of 1-2 mm/yr. From ~10,000 to 6,000 years before present, the Bay supported only a thin, discontinuous fringe of salt marsh along the expanding perimeter (Atwater et al. 1979). Salt marsh sedimentation and organic accumulation were presumably not able to keep pace with the rise in sea level. Approximately 6,000 years ago sea level rise slowed to its current rate. In the Bay, this allowed marsh accretion to keep pace with submergence. Evidence from Bay marsh cores indicates that during the past 6,000 years a continuous marsh fringe formed around the Bay and expanded landward, as sea level continued to rise.

Human Intervention. A review of historic and recent topographic maps of the area illustrates the changes that have occurred from the 1850s through the present. In 1857, only the bayward two of the three islands that now comprise Bair Island existed as islands; the area that is now Inner Bair was part of the mainland. There were no structures or levees and the entire Bair Island was tidal salt marsh. There were no significant changes between 1857 and 1897, except for a 10-acre area at the confluence of Corkscrew Slough and Redwood Creek, which was diked for use as a fishing village in 1869 (SLC 1977). The 1897 map shows what appears to be Cordilleras Creek discharging to Smith Slough through a small tidal channel on what is now Inner Bair Island. Around the turn of the century, Bair Island was included in several attempts to reclaim marshplain land for agricultural use. A levee around the outer edge of Outer Bair Island, possibly constructed around 1910 (SLC 1977), is shown in the 1931 map (Appendix E). The descriptive report accompanying this map states, "the area between Steinberger and Redwood Sloughs, some of which was at one time reclaimed land, has again reverted to marsh due to the breaking and overflowing of the confining levees. These marshes lie about one foot below extreme high tide. The area is traversed by numerous small sloughs."

Between 1946 and 1952, Leslie Salt Company partitioned most of Middle and Outer Bair Island with levees for use as salt evaporation ponds (SLC 1977). Salt production on Bair Island was discontinued in 1965, when the ponds were drained and abandoned. Although the date of levee construction for Inner Bair Island is not provided in the existing literature (SLC 1977; RTC 1991), we assume that they were constructed at the same time as the Middle and Outer Bair Island levees (1948-1952). This is consistent with the 1959 USGS topographic map that shows Inner Bair leveed. The 1959 map also shows Smith Slough and the borrow ditches south and southwest of Inner Bair in their current locations. It appears that when Inner Bair Island was leveed, a large meander bend in Smith Slough was cut off and leveed within the island, adding acreage to Inner Bair Island that was formerly part of Middle Bair. The borrow ditches were probably created during construction of the Inner Bair levee.

In 1973, Mobil Oil Estates purchased Bair Island and the Redwood Peninsula, where the Redwood Shores development now stands, from Leslie Salt Company. Much of Outer Bair Island was transferred to the California State Lands Commission (SLC) as part of the transaction or as mitigation for marsh loss during the development of Redwood Shores. Tidal action was restored to a large part of Outer Bair Island in the late 1970's and early 1980's through a series of planned and unplanned levee breaches.

The locations of the major sloughs have remained essentially unchanged between 1857 and the present, based on a comparison of the historic maps with the recent USGS topographic map (USGS 1973). Flow patterns in the sloughs, however, appear to have changed over time. Leveeing decreased tidal flows through the sloughs. In addition, Redwood Creek dredging, which began in 1955 and continues to the present, made Redwood Creek a more efficient tidal conveyance channel. Together, these changes would have had the effect of shifting Corkscrew and Smith Slough tidal flows towards Redwood Creek and making Steinberger Slough shallower from lack of tidal scouring. These results are supported by observations from recent aerial photographs (February 18, 2000). The photographs show that a reach of Steinberger Slough between Smith and Corkscrew Slough is dry at low tides, meaning that Smith Slough and the lower part of Steinberger Slough drain toward Redwood Creek. Also, the existing tidal drainage divide for Corkscrew Slough is in the western part of the channel near Steinberger Slough, meaning that most of Corkscrew Slough drains to Redwood Creek.

As recently as 1975, Steinberger Slough did not drain directly to the Bay at low tide. The USGS topographic map (1959, revised in 1968 and 1973) and old bathymetric maps (NOS 1975) show Steinberger Slough draining at low tide to Bay Slough and from there to Belmont Slough before discharging to the Bay. More recent bathymetric maps (NOS 1989 and NOS 1995) and low-tide aerial photographs (February 2000) show Steinberger Slough discharging directly to the Bay rather than Bay Slough. The former drainage pattern through Bay Slough was probably a remnant feature of the historical marsh. Steinberger and Bay Slough appear to have been one continuous internal marsh channel that has now become directly connected to the Bay by hundreds of years of sea level rise and shoreline erosion.

The bayward shoreline of Bair Island has experienced both aggradation and erosion, first aggrading from 250 to 1000 feet during the hydraulic mining era (as reflected on the 1857 and 1897 maps), then eroding between 1897 and 1931 and between 1931 and 1959. Relative to its position in 1857, the current shoreline has receded as much as 700 feet in some locations, but has aggraded approximately 200 feet in others. In addition to lateral movement of the marsh edge, the marshplain elevations of areas that were leveed on Inner, Middle, and Outer Bair Islands have subsided (see Existing Conditions section below).

3.1.2 Biological

Historically, Bair Island was part of a large complex of tidal marshes and mudflats located along southern San Francisco Bay. The numerous anthropogenic changes discussed in the previous section have replaced historic tidal salt marsh and fragmented the remaining habitat within the Bair Island complex. Wildlife use on the island complex has shifted over the years as these changes have occurred. In general, wildlife species that were historically supported by Bair Island are still present, only in somewhat diminished diversity and numbers due to the fragmentation and conversion of habitat (see Appendix D for a detailed description of existing wildlife resources). There are, however, some notable changes in nesting habitat on Bair Island.

The federally endangered Least Tern (*Sterna antillarum*) and the state protected Caspian Tern (*Sterna caspia*) both formerly nested on Bair Island. These two tern species have not nested at Bair Island since the early 1980's. Loss of these nesting colonies may have been related to loss of nesting habitat to vegetation encroachment, loss of nesting habitat when tidal action was restored to portions of Outer Bair Island, and depredation by non-native red fox (*Vulpes vulpes regalis*). Currently, a small colony of Forster's Terns (*Sterna forsteri)* occurs in the western portion of Middle Bair Island that moves from year to year.

The same scenario likely is true of the threatened Western Snowy Plover (*Charadrius nivosus nivosus*). Western Snowy Plovers were reported from Bair Island during the breeding season in the 1960s and early 1970s (though no nests were found); they have not been detected since (Page and Stenzel 1981). Black-crowned Night Herons (*Nycticorax nycticorax),* Great Egrets (*Ardea alba*) and Snowy Egrets (*Egretta thula*) formerly nested on Bair Island, but no longer actively nest on site (Ryan and Parkin 1998). The latter three species, in the process of nesting, eventually destroyed the shrubs and small trees in which they made nests, and since have moved to shrubs nearby at Redwood Shores. Depredation by non-native red foxes likely also played a role in the demise of these nesting species.

3.2 EXISTING CONDITIONS

The following is a brief description of the existing physical and biological conditions at Bair Island. Expanded descriptions of the existing physical conditions can be found in Appendix E and the existing biological conditions in Appendix D.

3.2.1 Physical

Land Use and Infrastructure. The site currently consists of leveed, inactive salt ponds, restored tidal marsh, supra-tidal dredged material disposal areas, and remnant historical marsh (Figure 5). Part of Inner Bair is owned by the San Carlos Airport and maintained as a safety area for emergency landings.

Infrastructure within the area proposed for restoration includes the South Bayside System Authority (SBSA) sewer line, a PG&E transmission tower, and a slide-gated culvert at Inner Bair (Figure 6). The SBSA line runs northwest underneath the Inner Bair Island levee from the Whipple Avenue interchange, across/under the western Inner Bair borrow ditch, and along the San Carlos Airport property. The PG&E transmission tower is located on the Inner Bair levee, near the eastern tip of the island. Infrastructure also includes existing levees (many abandoned), which are discussed in the next sub-section. Adjacent infrastructure includes the Port of Redwood City and Pete's Harbor. Redwood Creek is dredged for use as a shipping channel to service the Port of Redwood City. A part of Pete's Harbor, referred to as the Outer Harbor, is located in Smith Slough east of Inner Bair Island.

Marshplain Topography. Representative elevations for natural marshplains surveyed at Bair Island outboard of the leveed islands average 3.4 feet NGVD (natural pickleweed elevations range between 2.1 and 4.8 feet NGVD), or approximately the local MHW elevation, and represents the target elevation for the restoration of tidal wetlands. In contrast, subsidence has caused marshplains within the leveed salt ponds to lower by several feet below natural marshplain elevations. Inner Bair Island is at about 0.0 feet NGVD, Middle Bair about 1.0 feet NGVD, and Outer Bair at about 1.1 feet NGVD (Appendix E). The total subsidence of these areas from the target elevation, therefore, ranges from about 2.2 to 3.4 feet.

Tidal Characteristics. Tidal characteristics at the Redwood Creek tide gauge are shown in Table 1. Mean tide conditions are from the National Ocean Service (NOS, 2000). The 10- and 100-year estimated high tides are from the U.S. Army Corps of Engineers (USACE, 1984). The published tide data presented in Table 1 were checked for consistency with elevations from the field surveys used in this study (Towill 2000) using a tidal datum analysis based on one month of measured tides. Any future construction work at the site will need to use a vertical datum consistent with the surveys for this planning study (Towill 2000).

Table 1. Tide Characteristics at Redwood Creek, Channel Marker No. 8, San Francisco Bay

	Elevation	
	MLLW (feet)	NGVD (feet)
Estimated 100-Year High Tide	11.2	7.3*
Estimated 10-Year High Tide	10.5	6.6
Mean Higher High Water (MHHW)	8.1	4.0
Mean High Water (MHW)	7.5	3.3
Mean Tide Level (MTL)	4.3	0.2
National Geodetic Vertical Datum , 1929 (NGVD)	4.2	0.0
Mean Low Water (MLW)	1.2	-3.0
Mean Lower Low Water (MLLW)	0.00	-4.2

*Adopted elevation: adopted by the USACE from the smoothed profile of calculated 100-year tides.
Sources: NOS (2000), USACE (1984), PWA tidal datum analysis.
Note: NOS (2000) data are based on tide measurements between 1997 and 2000.

3.2.2 Hydrography

Redwood Creek, Steinberger Slough, Corkscrew Slough, and Smith Slough are the major tidal channels adjacent to Inner, Middle, and Outer Bair Islands. Outer Bair Island is bordered by an approximately 3000-foot wide outboard mudflat that is exposed at low tide. Shallow water continues offshore to the deepwater shipping channel through South San Francisco Bay, approximately 6,000 feet offshore of Outer Bair.

Redwood Creek, because it is dredged for use as a shipping channel, is the largest and deepest of the Bair Island sloughs. Most of the tidal exchange for the Bair Island slough system is through Redwood Creek. Smith Slough and most of Corkscrew Slough drain to Redwood Creek. The southern part of Steinberger Slough, between Smith and Corkscrew Sloughs, drains through Smith Slough to Redwood Creek. The remainder of Steinberger Slough drains directly to the Bay. The western 3000 feet (approximate) of Corkscrew Slough drains to Steinberger Slough and from there to the Bay.

On-site Drainage. Water levels in the inactive salt ponds on Inner, Middle and Outer Bair Islands are controlled by ponding of direct rainfall, evaporation, and levee seepage. Seepage between the ponds and adjacent channels occurs in both directions (into and out of the pond), depending on relative water levels. A slide-gated culvert on Inner Bair may offer some level of drainage connection between the pond interior and Smith Slough. The slide gate and culvert appear to be at least a decade old and have been observed by San Mateo County Mosquito Abatement District staff to be filled with debris (D. Jewell, pers. comm.). During field surveys conducted during March 2000, observed water levels were approximately –0.5 feet NGVD at Inner Bair, 0.1 to 1.3 feet NGVD at Middle Bair (varied by pond and date of survey), and 1.1 feet NGVD at Outer Bair.

Until recently, water in the Middle and Outer Bair salt ponds was siphoned periodically during the rainy season to keep ponding, and associated mosquito production, to a minimum. According to Dennis Jewell, Supervisor with the San Mateo County Mosquito Abatement

District, temporary siphons were used to drain Middle and Outer Bair beginning in the late 1970s or early 1980s (D. Jewell, pers. comm.). Mobil Oil installed and operated the siphons originally, and then the Mosquito Abatement District continued operations. The Mosquito Abatement District siphoned during the rainy season; by June, the ponds would usually be dry. The Mosquito Abatement District discontinued siphon operations at Bair Island in 2000 due to lack of funds and staffing. The siphons are constructed of white PVC pipe and are still visible at the site today (PWA site reconnaissance, March 2000).

It appears that Inner Bair Island has never been siphoned. Siphoning for mosquito control was not used at Inner Bair because the area is easily accessible for other types of mosquito abatement treatment (D. Jewell, pers. comm.). In addition, there are potential vandalism problems associated with storage of siphons at Inner Bair.

Off-site Drainage. Three major creeks—Redwood, Cordilleras, and Pulgas Creeks—convey surface runoff from the hillsides southwest of Bair Island to San Francisco Bay (Figure 5). Redwood Creek continues all the way to the Bay, while Cordilleras and Pulgas Creeks flow into the western Inner Bair borrow ditch and from there to Smith Slough and Steinberger Slough. Smith Slough drains to Redwood Creek and from there to the Bay. The part of Steinberger Slough near Smith Slough drains directly to the Bay only during higher water levels. The storm drain systems of Redwood City and San Carlos discharge storm runoff into Redwood Creek and Pulgas Creek, respectively, through a combination of gravity drainage and pumping. Additionally, there are several areas that discharge directly to the tidal sloughs or to the Bay itself, either via pump stations or gravity drainage.

<u>Redwood Creek.</u> Redwood Creek drains an area of 9.3 square miles, almost entirely within the city limits of Redwood City. The watershed is largely developed, ranging from medium-density residential areas in the hills to high-density residential, commercial, and industrial areas near the Bay.

<u>Cordilleras Creek.</u> Cordilleras Creek drains a 3.6-square mile watershed and forms much of the border between Redwood City and San Carlos. Most of the channel remains in its natural state without significant human alterations. The creek passes through concrete box culverts under Highway 101 before discharging into the western Inner Bair borrow ditch. Tidal influence extends 1000 feet up the creek from the Bay to Redwood High School. Cordilleras Creek is not connected to the main storm drain systems of either Redwood City or San Carlos (CFCCNA, 1999).

<u>Pulgas Creek.</u> Pulgas Creek collects surface runoff from a 3.6-square mile area in central San Carlos and a small part of Belmont (FIA, 1977). It passes through concrete box culverts under Highway 101, approximately 700 feet upstream of its entrance to Steinberger Slough. The creek has been channelized east of Old County Road, and lined with levees east of Highway 101 to protect adjacent areas (primarily the San Carlos Airport) against tidal flooding (FIA, 1977).

<u>Steinberger Slough and San Francisco Bay.</u> There are three main drainage areas northwest of Bair Island that discharge to Steinberger Slough or directly to San Francisco Bay. Storm water runoff from the San Carlos Airport is accommodated by several on-site pump stations (FIA,

1977) that likely drain to Steinberger Slough. Runoff from northern San Carlos and Belmont that drains to a holding pond in Phelps Slough is pumped into Steinberger Slough (KJC, 1986). Runoff from Redwood Shores is routed to a controlled interior lagoon. Some of the flows are collected at pump stations (C. Chang, pers. comm.) and some are stored until they can be released via gravity drainage at low tide to Steinberger Slough or to the Bay (KJC, 1986).

Tidal Flooding. FEMA flood mapping shows Bair Island completely within the 100-year floodplain in a region dominated by tidal flooding. It appears, however, that levee improvements made since the date of FEMA mapping now protect Inner Bair from 100-year flooding. There are no levees along Highway 101 where it parallels the western Inner Bair borrow ditch. The elevation of the highway in this region ranges from 8.6 to 10.9 feet NGVD (Caltrans, 1999), which is higher than the 100-year tide level. The lowest point of the highway infrastructure appears to be part of the Whipple Avenue interchange off-ramp, at an elevation of 6.8 feet NGVD.

Flooding on Regional Creeks. The adjacent watersheds of Redwood, Cordilleras, and Pulgas Creeks experience approximately the same rainfall and tides. Because of these similarities, creek flooding typically occurs during the same storm events. Major surface runoff flooding events on these creeks occurred in 1940, 1955, 1958, 1973, 1982, and 1983 (USACE, 1989).

<u>Redwood Creek.</u> The flood events prior to the 1967 storm drain project seem to be caused largely by high creek flows and the overtopping of channel banks, while later flood events appear to be caused by backed-up storm drain systems and limited culvert capacity (USACE 1989).

<u>Cordilleras Creek</u>. Flooding on Cordilleras Creek is exacerbated by erosion in the upper watershed, resulting in deposition and blockage downstream in the flat, low-lying areas. The more serious flooding on this creek occurs between El Camino Real and Highway 101 (CFCCNA 1999). In more extreme (50- and 100-year) events, flow from Cordilleras Creek backs up at El Camino Real and joins with ponded areas to the northwest created by overflows from Brittan and Pulgas Creeks (Appendix E) (FIA 1977).

<u>Pulgas Creek.</u> Overflow from Pulgas Creek causes flooding in the industrial area between El Camino Real and Highway 101. The pump station at Industrial Road is not large enough to relieve flooding from extreme events in this area (FIA 1977). Flooding in the industrial area is most severe when drainage is limited by high tides. Due to persistent minor flooding in the industrial area, the city plans to install two new culverts under city streets upstream of Highway 101 as part of a long-term flood management initiative (D. Gilbert, pers. comm.). Caltrans recently installed additional culverts under Highway 101 to accommodate the expected higher capacity upstream (S. Goodson, pers. comm.).

Wind Climate. Wind data for Bair Island were collected by USGS for approximately one-year (J. Dingler, pers. comm.). According to these measurements, the primary wind direction is from the west-northwest, with an average wind speed of 6.2 mph. The Bair Island data show seasonal and diurnal patterns typical of San Francisco Bay, where on-shore sea breezes create strong summer afternoon winds and winter storms bring high velocity, shorter duration winds from the south-southeast.

3.2.3 Biological

In July 2000, an existing biological conditions document was produced to assess and map the existing biological conditions of the Bair Island complex (H. T. Harvey & Associates 2000). During the mapping of Bair Island, seven different habitat types were identified (Figure 7). These included tidal salt marsh, muted tidal salt marsh, diked salt marsh, seasonally ponded wetlands, aquatic/open water (including portions of subtidal and intertidal slough channels that adjoin the site), shell mounds, ruderal upland, and developed. Table 2 lists the quantity (in acres) of each habitat type that is present within the project boundaries of the Bair Island Restoration Project. Each of these habitats is briefly described below, and the locations of the habitats are demarcated on Figure 7.

Table 2. Habitat areas for Inner, Middle and Outer Bair Island.

LOCATION	HABITAT	ACRES
Inner Bair Island	Aquatic	48.71
	Developed	8.47
	Diked Salt Marsh	9.06
	Ruderal Upland	187.89
	Seasonally Ponded Wetland	32.82
	Tidal Salt Marsh	36.90
	Total	**323.83**
Middle Bair Island	Aquatic	112.01
	Diked Salt Marsh	553.64
	Ruderal Upland	38.02
	Tidal Salt Marsh	192.54
	Total	**896.21**
Outer Bair Island	Aquatic	100.21
	Diked Salt Marsh	468.90
	Muted Salt Marsh	51.77
	Ruderal Upland	141.45
	Shell Mounds	5.63
	Tidal Salt Marsh	647.13
	Total	**1415.09**
	Overall Acreage	**2635.13**

Tidal Salt Marsh. Tidal salt marsh occurs along the outboard side of the existing levees, as well as in the former salt ponds in the northwest section of Outer Bair where the levees have been allowed to breach. The tidal salt marsh within these former salt ponds is at a slightly lower elevation than the outboard marshes. This results in a plant community comprising an equal mix of cordgrass (*Spartina foliosa*) and pickleweed (*Salicornia virginica*). The slightly higher elevation outboard marshes are predominantly composed of pickleweed. The outboard marsh serves as the ideal target habitat for the restoration effort, with the marsh inside the former salt ponds on the west side of Outer Bair providing insight into the evolution of the sites once tidal action is returned.

Other common plant species found in the tidal salt marsh are alkali heath (*Frankenia salina*), saltmarsh dodder (*Cuscuta salina*) and jaumea (*Jaumea carnosa*). Marsh gumplant (*Grindelia stricta* var. *angustifolia*) occurs at higher elevations, as well as along the ecotone between tidal salt marsh and ruderal upland habitat

Tidal salt marsh supports a variety of vertebrate wildlife species, including the federally endangered salt marsh harvest mouse, and the federally endangered California Clapper Rail. Shorebirds such as Willets (*Catoptrophorus semipalmatus*), and dowitchers (*Limnodromus* spp). are likely to occur here as well.

Muted Tidal Salt Marsh. One pond on eastern Outer Bair Island (Figure 7) contains deteriorated flapgate structures that are no longer functional and allow muted tidal action within the small leveed area. This area was leveed off in a failed attempt to protect Least Tern nesting habitat. Currently, the area consists of a mix of cordgrass and pickleweed. Wildlife use is similar to that in tidal salt marsh.

Diked Salt Marsh. This habitat type is largely found on the interior of the former salt ponds on Inner, Middle and Outer Bair Island (Figure 7). These areas will be the primary targets for restoration to tidal salt marsh. The diked salt marsh habitat generally consists of pickleweed interspersed with mudflats and small open water areas. The quality of the habitat between the four former salt ponds is highly variable. The former salt pond on Outer Bair Island has the highest quality habitat with over 50% cover by pickleweed that has moderate vigor. The westernmost pond on Middle Bair has less than 50% cover by pickleweed of moderate to low vigor, while the two remaining diked salt marsh areas on Middle Bair have approximately 30% cover by pickleweed of low vigor (Figure 7). The latter two ponds also have a higher occurrence of brass buttons and bare soil/salt pan. Wildlife use is significantly diminished from that in tidal salt marsh. Clapper Rails are likely to be present in this habitat only along inboard sloughs and channels where sufficient cordgrass is present. Diked salt marsh also represents only poor to moderate quality habitat for salt marsh harvest mice.

Seasonally Ponded Wetlands. These wetlands are located in slightly lower topographic depressions within the levees of Inner Bair Island (Figure 7). The changes in microtopography responsible for small patches of seasonal wetlands are very numerous, and made precise field delineation of all the patches virtually impossible due to time and budgetary constraints. However, soil pits were dug within Inner Bair Island to determine the status of these seasonal wetland areas, and the results were extrapolated to all of Inner Bair using the habitat signatures present on the aerial photography. These wetland areas, supported largely by incident rainfall, were dominated by rabbitsfoot grass (*Polypogon monspeliensis*) and brass buttons (*Cotula coronopifolia*) with patches of pickleweed, spearscale (*Atriplex triangularis*) and alkali heath also occurring throughout. These ponds support feeding shorebirds, such as sandpipers (*Calidris* spp.) and Willets, in winter, as well as waterfowl and gulls.

Aquatic/Open Water. Aquatic habitat occurs within the low-flow channel of the creeks, slough channels and borrow ditches throughout the Bair Island complex. This deep-water habitat does not support either emergent or terrestrial vegetation.

Wildlife likely to occur in this habitat include fish such as the bay ray (*Myliobatis californica*), bay pipefish (*Syngnathus leptorhynchus*), bay goby (*Lepidogobius lepidus*), shiner surfperch (*Cymatogaster aggregata*), starry flounder (*Platichthys stellatus*), and English sole (*Parophrys vetulus*). Birds likely to occur here include Western Grebe (*Aecmophorus occidentalis*), American Coot (*Fulica americana*), gulls, and various waterfowl species, such as scaup (*Aythya* spp.). Harbor seals (*Phoca vitulina*) occur here as well.

Shell Mounds. A few small areas of exposed shell exist along the perimeter of Outer Bair Island along the San Francisco Bay (Figure 7). These areas are largely devoid of vegetation and are readily visible from the ground as well as from the aerial photography. Shell mounds may provide nesting substrate for American Avocets (*Recurvirostra americana*) and Killdeer (*Charadrius vociferus*).

Ruderal Upland. Ruderal habitat is generally characterized by an area of land that receives some sort of natural or anthropogenic disturbance on a regular basis that significantly alters the natural landscape. Ruderal communities are assemblages of plants that thrive in disturbed areas; in the San Francisco Bay area weedy, annual, non-native plants are typically the first species to colonize these sites following a disturbance.

The predominant ruderal species identified at Bair Island include Italian ryegrass (*Lolium multiflorum*), ripgut brome (*Bromus diandrus*), black mustard (*Brassica nigra*), wild radish (*Raphanus sativus*), Mediterranean barley (*Hordeum marinum* ssp. *gussoneanum*), wild oats (*Avena fatua*), yellow star-thistle (*Centaurea solstitialis*), common sow thistle (*Sonchus oleraceus*), bull thistle (*Cirsium vulgare*), bristly ox-tongue (*Picris echioides*), rabbitsfoot grass, brass buttons, alkali heath, and coyote brush (*Baccharis pilularis*).

This habitat may support a variety of songbirds, such as Song Sparrows *(Melospiza melodia*), House Finches (*Carpodacus mexicanus*), and Lesser Goldfinches (*Carduelis psaltria*). Various mammals, including brush rabbits (*Sylvilagus bachmani*) and California voles (*Microtus californicus*) are likely to occur here as well.

Developed. For the purpose of this analysis, developed habitat refers to the unvegetated trails that are present around the perimeter, and across the middle of, Inner Bair Island. The parking lot area adjacent to Whipple Avenue does contain some hardscape material, but the developed areas are mostly compacted soil. These areas do contain sporadic vegetation, generally consisting of ruderal vegetation around the perimeter trail (see Ruderal Upland description) and some brass buttons in the low spots along the trail down the middle of Inner Bair Island. This habitat does not support any significant wildlife.

3.2.4 Special-status Plant Species

The process of identifying special-status plant species for consideration involved two steps. First, a query of special-status plants in the California Natural Diversity Database (CNDDB)

Redwood Point quadrangle, and eight adjoining quads. Second, the California Native Plant Society Inventory (1994) was used to produce a similar list for San Mateo County. The habitat requirements and current distribution for each special-status species were the principal criteria used for inclusion in the list of potentially occurring species on site. Therefore, plants were considered on the basis of their occurrence in the broad categories of marshes and swamps, and valley and foothill grasslands that are most similar to the salt marsh, seasonal wetland, and ruderal habitats on site.

Many of the special-status plant species that occur in San Mateo County are found in habitat types that are not present on site. These habitat types include: dune and prairie habitats, coniferous habitats, woodland habitats, meadow and vernal pool habitats, and scrubs and chaparral habitats, and serpentine environments. In addition, the following sensitive habitats identified by the CDFG Rarefind Database query are not present on site: valley oak woodland, valley needlegrass grassland, and serpentine bunchgrass. A fourth sensitive habitat, northern coastal salt marsh, is prevalent on site.

A total of 41 special-status taxa occur in the area within similar habitats according to the CNPS inventory and the CDFG Rarefind Database. Of these, 37 species were dismissed due to the absence of suitable microhabitats (mostly serpentine substrates), and/or have been regarded as either extirpated from San Mateo County; their distribution has been reduced to historical occurrences, or they are considered extinct. Suitable habitat exists in the project area for only 4 species including: Contra Costa goldfields (*Lasthenia conjugens*), Point Reyes bird's beak (*Cordylanthus maritimus* ssp. *palustris*), Congdon's tarplant (*Hemizonia parryi* ssp. *condonii*), and marsh gumplant (*Grindelia stricta* var. *angustifolia*). Of these, the marsh gumplant was observed on site. Congdon's tarplant, Contra Costa goldfields and the Point Reyes bird's beak have not been observed, and detailed surveys for these species have not been conducted.

California sea-blite (*Suaeda californica*) was one of the species initially considered for the project goals. It is an extremely rare succulent shrub of the upper intertidal zone. In San Luis Obispo County, where the sole remaining natural populations of California sea-blite persist, plants colonize the course substrates of sandy salt marsh edges and marshy beach ridges. Extant populations are discontinuously distributed in a narrow band around Morro Bay in association with pickleweed, saltgrass, rush, and alkali heath. Populations are absent from the more interior portion of the marshlands (USFWS 1994). Relative to the pickleweed-dominated middle marsh plains typical of San Francisco Bay, substrates at favored sites are both well-drained and subject to high-energy waves and tides.

California sea-blite was probably never common in the San Francisco Bay except in the few, long-developed areas of sandy beach interface in Alameda and San Francisco counties (Baye et al 2000). Bair Island is a significant distance from the Bay mouth and is subject only to low-energy wind and waves; the proximity of intertidal mudflats drives the transport and deposition of fine-grained sediments; native plant communities are therefore mudflat colonizers. Sandy substrates suitable for supporting California sea-blite were probably never present on Bair Island. It is therefore very unlikely that an attempt to create a sandy intertidal habitat would succeed, even on Outer Bair, without significant mechanical inputs to fill with dredged sand and prevent fine sediment deposition and mixing. Furthermore, these techniques are incompatible with the restoration design, which hinges on the natural accumulation of fine sediments on the subsided sites. Therefore, development of habitat for California sea-blite will not be considered further in this restoration plan.

3.2.5 Listed Wildlife Species

Two species listed as Federally Endangered (FE) breed in high density on Outer Bair Island: the California Clapper Rail and salt marsh harvest mouse. The California Clapper Rail breeds only in the fully tidal salt marsh portions of Outer Bair Island. The salt marsh harvest mouse likely occurs on Middle Bair Island also, as there is much pickleweed present. Three listed species occur as seasonal residents, including the Western Snowy Plover (Federally Threatened, FT), California Least Tern (FE) and California Brown Pelican [*Pelecanus occidentalis* (FE)]; and two others, the steelhead [*Oncorhynchus mykiss* (FT)] and chinook salmon [*Oncorhynchus tshawytscha* (FT)], migrate through the area. The California Black Rail (State Threatened and Federal candidate) and Bank Swallow [*Riparia riparia* (State Threatened)] could occur rarely in the study area. The harbor seal, protected under the Marine Mammal Protection Act, hauls out and pups along the banks of Corkscrew Slough. The Alameda Song Sparrow (*Melospiza melodia pusillula*) and Salt Marsh Common Yellowthroat (*Geothlypis trichas sinuosa*) have been candidate species for federal and state listing, and are considered species of special concern by the State of California. The Alameda Song Sparrow is common in the salt marsh of Bair Island; the Salt Marsh Common Yellowthroat is likely sparse owing to a lack of willow thickets and *Scirpus* sp.

California Least Tern was one of the species initially considered for the project goals. These terns formerly nested on diked portions of Outer Bair that are not part of this restoration project. The likelihood of successfully creating breeding habitat in this location is slim, as years of management to preserve the former colony were not successful. In addition, the creation of nesting areas for the Least Tern is not compatible with the natural sedimentation processes necessary for tidal salt marsh development. Tidal salt marsh is the target habitat of this restoration as it serves as the primary habitat for the California Clapper Rail and salt marsh harvest mouse. Therefore, development of habitat for the Least Tern will not be considered further in this restoration plan.

4.0 SITE OPPORTUNITIES AND CONSTRAINTS

The Bair Island complex presents numerous restoration opportunities, including the return of approximately 1400 acres of Inner, Middle and Outer Bair Island to tidal salt marsh habitat. However, the site also offers many constraints to the proposed restoration effort, which range from existing infrastructure to sensitive wildlife species. A comprehensive list of these opportunities and constraints have been compiled in conjunction with the Technical Review Team (TRT), and are presented below.

4.1 PHYSICAL AND GEOMORPHIC OPPORTUNITIES

- *Estuarine sediment supply*. Estuarine sedimentation processes may be used to rebuild the subsided marshplain over time.
- *Natural vegetation processes*. Existing local marsh vegetation is expected to provide a source of seed and propagules for natural colonization of the restored marshes.
- *Existence of antecedent channel network*. Dendritic networks of antecedent channels are present in all the ponds, especially Middle and Outer Bair Islands. Scour is expected to occur first nearest the breaches, gradually headcutting back into the pond interiors. Some channels may need to be excavated in Inner Bair to provide tidal drainage.
- *Fill to elevations conducive for marsh vegetation colonization*. Fill can be used to raise ground elevations and create areas likely to colonize rapidly with marsh vegetation. Redwood Creek dredged material is a potential source of fill.
- *Create recreational and educational areas on Inner Bair Island*.
- *Provide data for future large-scale tidal wetland restoration projects in San Francisco Bay*.

4.2 PHYSICAL AND GEOMORPHIC CONSTRAINTS

- *Subsided ground elevations below vegetation colonization elevations*. The bottom elevations for Inner, Middle, and Outer Bair are subsided below natural marshplain elevations, and most areas are initially too low in the tidal frame for marsh plants to establish or survive. Average marshplain elevations are approximately 0.0 ft NGVD for Inner Bair and 1.0 ft NGVD for Middle and Outer Bair. Emergent marsh requires minimum elevations around 1.0 to 2.0 ft NGVD for seeds to germinate. Figure 8 compares initial elevations of restored tidal marshes in San Francisco Bay to the time it took each site to reach 50 % vegetative cover.
- *Sedimentation rates will limit rates of marsh evolution if fill material is not used*. The mudflats adjacent to Outer Bair Island are the primary source of sediment to the sloughs surrounding Bair Island and will be the primary source for the restored wetlands. Large winter storms deposit suspended sediments on the mudflats. These sediments are then resuspended by wave action and carried into the major sloughs adjacent to Bair Island on each tide. Sediment concentrations are lowest for channels further from the Bay such as Smith Slough. Although the Redwood Creek watershed will supply some sediment to the area, this source is not expected to be significant. Wind wave resuspension could also limit rates of sedimentation, though the extent of this effect is undefined. The islands are

large and high wind fetches could allow sizeable waves to generate within the islands, keeping sediments from depositing and scouring previously deposited sediments.

- *Limitations to natural channel formation*. In general, breaching at the locations of historic channels is expected to help reestablish the antecedent historic channels. The borrow ditches that ring the interior of the diked ponds can short-circuit the tidal flow, drawing tidal energy away from scouring of the historic channels and reestablishment of the natural channel system.
- *SBSA sewer pipeline on Inner Bair Island*. The existing levee over the pipeline will need to be enlarged to protect it from potential wave erosion once the site is breached. Access needs to be provided to the pipeline for regular visual inspections of the pipeline corridor; staging areas also need to be available in the likelihood of future repairs.
- *San Carlos Airport safety zone*. The San Carlos Airport property on Inner Bair Island requires measures to prevent the safety zone from flooding.
- *Induced Deposition in the Redwood Creek shipping channel*. The shipping channel is by far the largest and most efficient channel to convey tidal waters to the restored Inner and Middle Bair Islands. Sediment transport modeling conducted in support of restoration planning indicates that increasing tidal prism through the shipping channel could result in faster siltation of this channel and necessitate more frequent dredging. The restoration plan must avoid or mitigate for these potential impacts.
- *Tidal Velocities in Pete's Outer Harbor*. Hydraulic modeling conducted in support of restoration planning indicates that the most direct restoration approach – simply breaching the islands at historic slough locations – could result in much stronger tidal currents through the Outer Harbor. The restoration plan must avoid or mitigate for these potential impacts.
- *Flooding on Redwood, Pulgas and Cordilleras Creeks*. Significant impacts to flooding on these creeks must be avoided or mitigated.
- *Protection of other infrastructure*. Flood protection levees on Redwood Creek and Steinberger Slough will require protection from potential increased erosion due to any increases in tidal scour. PG&E will need continued access to their towers and maintenance boardwalks.

4.3 BIOLOGICAL OPPORTUNITIES

- *Restore key estuarine ecological processes (e.g., nutrient exchange) by increasing connectivity of the marsh and the Bay*. The interior areas of Bair Island are physically separated from the Bay.
- *Restore approximately 1400 acres of tidal wetland and upland transition habitat.*
- *Convert existing upland to tidal wetland habitat both by lowering portions of the perimeter levees throughout the project site and creating new wetland habitat from upland areas on Inner Bair Island.* Although the majority of Middle and Outer Bair Island are diked wetland habitats, much of Inner Bair Island is upland habitat.
- *Create new areas conducive to seal haul-out and pupping, such as those along Corkscrew Slough.*
- *Maximize topographic relief between upland areas and slough channels to restore habitat diversity via expanded ecotones.*

- *Restore habitat that supports special-status plant and animal species (such as the salt marsh harvest mouse and California Clapper Rail).*
- *Provide data for future large-scale tidal wetland restoration projects in San Francisco Bay.* Since the opportunity exists for tidal wetland restoration in much of the South Bay, the Bair Island Restoration project provides a unique opportunity to gather information that can be applied to the planning, design, and implementation of other large-scale restoration projects.
- *Reduce and manage predation by grading and breaching levees to create barriers to predators.*
- *Create islands within tidal marsh habitat to provide high-tide refugia for target wildlife.*
- *Create seasonal wetland areas.* Opportunities for seasonal or diked wetland habitat creation are present at Inner Bair Island.
- *Reduce mosquito impacts to local communities.*

4.4 BIOLOGICAL CONSTRAINTS

- *Existing seal haul out and pupping area habitat on Corkscrew Slough may be impacted.* Placement of a flow constriction in Corkscrew Slough may affect harbor seal access to haul-out sites in the slough. A barrier located between the two haul-out sites could impede access to at least one of the sites.
- *Ponding of water on Inner Bair may increase bird use, and therefore increase aircraft bird strike potential.* The restoration of seasonal wetland habitat on Inner Bair Island could increase the risk of bird strikes.
- *Creation of habitat for endangered species may impede future maintenance activities along the SBSA sewer line.* The restoration of salt marsh habitat immediately adjacent to the SBSA sewer line could cause future permitting difficulties for maintenance activities.
- *Existing special status-species (especially the salt marsh harvest mouse) habitat on-site will be disturbed by construction activities and flooding of existing habitat.* Much of the area within Middle and Outer Bair Island slated for restoration may currently provide some habitat for the salt marsh harvest mouse. Furthermore, tidal marshes on the outboard side of existing levees may currently support California Clapper Rails and salt marsh harvest mice.
- *Invasion of newly restored habitats by non-native or unwanted organisms.* Non-native cordgrass invasion is a Bay-wide problem and the restoration of Bair Island could contribute to its further expansion.
- *Increase in disturbance to wildlife from recreation and maintenance of recreational infrastructure with changes in habitat on Inner Bair Island.* The restoration of endangered species habitat may not be compatible with some recreational activities.
- *Impacts to existing wetlands from dredge and fill activities, and from increased tidal prism scouring of outboard marshes.*

5.0 DESIGN APPROACH

The restoration design approach is to create an initial site template that will guide the action of natural physical and biological processes after breaching to form a self-sustaining tidal marsh system. The design approach relies as much as possible upon natural estuarine sedimentation and biological succession. This approach is consistent with recommendations by the San Francisco Bay Area Wetlands Ecosystem Goals Project (Goals Project), a collaborative planning effort with input from numerous regional wetland and restoration scientists.

The most direct and simple restoration approach would be to breach each island at several historic channel locations and allow natural estuarine sedimentation and biological succession to gradually create tidal marsh habitat. However, the consideration of several infrastructure constraints (safety considerations for the San Carlos Airport, protection of the SBSA sewer line on Inner Bair, not worsening siltation in the Redwood Creek shipping channel, and avoiding impacts to navigation at Pete’s Outer Harbor) made it necessary to include some substantial modifications to this direct and simple approach. The need to address these constraints affected the formulation of restoration alternatives.

Section 5.1 describes the template design approach and provides an overview of tidal marsh evolution after restoration. Section 5.2 describes the infrastructure constraints and solution approaches. Section 5.3 provides an overview of the design features common to many of the restoration alternatives. The information in Sections 5.2 and 5.3 are important background to the alternatives discussion in Section 6.

The design approach also included using hydraulic and sediment transport modeling to assess potential project impacts and evaluation solution approaches. This modeling is described in Appendix A.

5.1 SITE TEMPLATE APPROACH AND EVOLUTION OF RESTORED TIDAL MARSH

The restoration design approach is to create an initial site template that relies primarily on natural estuarine sedimentation to raise subsided site elevations, tidal scour to reestablish antecedent tidal channels, and natural plant colonization to establish marsh vegetation. Direct interventions such as grading and filling are minimized, where possible, in the design. However, any target habitat features that may not evolve on their own or may not evolve as rapidly as needed to meet the habitat goals or site constraints are either included in the design template or given a “jump start” to develop more quickly.

Important to the design approach is an understanding of how tidal habitats will likely evolve over time. The establishment of salt marsh habitat in subsided sites such as Inner, Middle, and Outer Bair Islands requires the accumulation of sediment until mudflats are high enough for plant colonization. Figure 9 illustrates conceptually how the marsh plain for a subsided site is anticipated to evolve in response to estuarine sedimentation, scour, and plant establishment processes. Initially, the site is low in elevation relative to the tidal frame, and consists primarily of intertidal mudflat with vegetation at the higher elevations. As sedimentation raises elevations, vegetation establishes and tidal flows scour and deepen the channels. Once the mudflats reach a high enough elevation relative to the tidal frame, pioneer plant colonization can occur. A vegetated marsh plain forms through lateral expansion of rhizomes from each established plant on the mudflat, and from plants along the site perimeter. As the marsh plain rises within the tidal frame, estuarine sediment accretions slows exponentially until a marsh plain forms at an elevation within a few decimeters of MHHW (Atwater et al. 1979). The solid line in Figure 10 illustrates conceptually how the marsh plain is anticipated to evolve in response to estuarine sedimentation processes, from subtidal, to intertidal mudflat, to initial mudflat colonization by *Spartina* sp., to ultimately a fully mature vegetated, pickleweed-dominated marsh plain.

The primary determinant of whether a sustainable vegetated marsh will form is whether vertical accumulation of sediment relative to sea level will build up mudflat elevations high enough for emergent vegetation colonization. Elevation gain relative to sea level in any given time period is a function of accumulation, erosion, and relative sea level rise. In general there is a tendency for accumulation processes to decline and for erosive processes to increase as mudflat elevations increase.

Accumulation in subsided restored sites is mainly dependent on estuarine suspended sediment concentrations in the tidal flows feeding the site, and the depth and frequency of tidal inundation. Suspended sediment concentrations in the water column on the incoming tide are influenced by proximity to intertidal mudflats or shallows, wave action, and depth of the water column. Depth and frequency of tidal inundation depend on the mudflat elevation and tides. As mudflats build higher, they are inundated less deeply and less frequently, reducing net sedimentation rates.

Erosion of estuarine sediments is mainly dependent on wind-wave action and tidal currents. Wind-waves are generated when wind blows over a length of water (a distance called the wind "fetch"). Wave height is positively correlated with wind speed, fetch length, and water depth. For a given wave height, erosion is greater in shallow water than in deeper water. Tidal currents are generally quite small except where tidal sloughs are forming.

Relative sea level rise is mainly a function of eustatic (global) sea level rise and local subsidence. Ocean thermal expansion and glacial melting in response to global warming drive global sea level changes. Predictions of global sea level rise range from 0.2 feet to 1.1 feet over the next 50 years. For this study, we used a mid-range estimate of 0.5 feet (IPCC 1996).[1] Based on a 1987 San Francisco Bay Conservation and Development Commission (BCDC) report that characterizes subsidence throughout the San Francisco Bay area, local subsidence at the site is approximately –0.006 feet/year, or –0.3 feet in 50 years. This estimate may be high, however, since it is based on an extrapolation of historic subsidence due to groundwater pumping and tectonic movement. There is evidence to suggest that groundwater pumping has slowed considerably since the period of time upon which the above local subsidence estimate is based (BCDC, 1987).

[1] During the course of this study, updated sea level rise estimates of 0.6 ft over the next 50 years were released (IPCC 2000). These are very close the values used in this study.

In addition to limited sediment supply, two other factors can retard the physical evolution of a subsided restored site to a vegetated marsh: damped tides and internally-generated wind waves. Good marshplain drainage is important to marsh development. Poor drainage from damped tides can limit sediment supply to the restored site and inhibit plant colonization. Internally generated wind waves prevent deposition or resuspend deposited estuarine muds. For wave-exposed sites with long wind fetches, the rate of net mudflat accretion is diminished as it builds in elevation. For some subsided sites with long wind fetches, there is a potential for wind wave action to create permanent intertidal mudflats instead of marshplains (Figure 10) unless the sites are partially filled.

5.1.1 Expected Evolution of Wildlife Communities

Restoration of other tidal marsh sites in the San Francisco Bay area has resulted in expected shifts in wildlife communities. When sites are first exposed to tidal action, mudflats are typically created, resulting in rich invertebrate communities and large numbers of foraging shorebirds, especially during winter. As vegetation develops (e.g., annual pickleweed, and eventually cordgrass), the bird community generally shifts to larger shorebirds, and lower abundance. When mature cordgrass and pickleweed marsh has been established, bird abundance (for many species) and diversity can be quite low, but habitat becomes suitable for the special-status California Clapper Rail and salt marsh harvest mouse, as well as a suite of species found in such tidal marshes.

5.2 APPROACHES FOR ADDRESSING INFRASTRUCTURE CONSTRAINTS

Site conditions and constraints that had a significant effect on the restoration design include: safety requirements of the San Carlos Airport, the SBSA pipeline on Inner Bair, sedimentation in the Redwood Creek shipping channel, and tidal velocities in Pete's Outer Harbor. Each of these constraints and the solution approaches are described below. The restoration alternatives presented in Section 6 use various combinations of these solution approaches.

5.2.1. Safety requirements of the San Carlos Airport

Flood protection for the San Carlos Airport safety zone will require either leveeing and draining the safety zone or filling this area to above tidal elevations (Figure 3). To reduce the potential for bird strike hazards, the restoration approach is to create vegetated marsh habitat on Inner Bair Island and minimize ponded open water areas. Vegetated marsh habitat is not favored by the bird species that pose the greatest strike hazard (see Appendix C).

Natural sedimentation and plant establishment processes would not be expected to result in substantial areas of vegetated marsh at Inner Bair for several decades, or longer. Because this timeframe is not acceptable from a hazard perspective, other approaches are used. Two approaches to creating vegetated marsh are to fill Inner Bair to high intertidal elevations at which vegetation will rapidly establish, or to manage Inner Bair as a muted tidal marsh. In the managed marsh scenario, the depth of ponding on Inner Bair would be limited to depths consistent with vegetation establishment and survival.

5.2.2 SBSA pipeline on Inner Bair

The levee covering the SBSA force main must be protected from wave erosion after restoration. In addition, the SBSA requires continued maintenance access and a means of detecting leaks. The solution approach presumed for the restoration plan is to widen the levee crest. This design constraint will need to be evaluated in more detail in final design.

5.2.3 Redwood Creek Shipping Channel Siltation

Preliminary hydrodynamic and sediment transport modeling indicated that breaching Middle and Inner Bair at the historic channel locations, without including other flow modifications in the design, would result in more rapid sedimentation of the Redwood Creek shipping channel and require more frequent dredging, compared to existing conditions. The restoration approach to prevent this is to restrict tidal flows in Smith and Corkscrew Sloughs, rerouting most or all flow from the restored ponds through Steinberger Slough rather than Redwood Creek.

The rerouting of flows is necessary to avoid drawing large volumes of sediment-laden water through the Redwood Creek shipping channel, where low flow velocities cause the sediment to deposit and rapidly silt in the channel (Appendix B). Because Redwood Creek is dredged and is vastly oversized in comparison to Steinberger Slough (Figure 11), tidal flows to Middle and Inner Bair tend to flow preferentially though Redwood Creek. Even with the larger restored flows, velocities in Redwood Creek are low and sedimentation occurs throughout the tide cycle. Sediment transport modeling results (Appendix B) indicate that the increase in sediment-laden flows through Redwood Creek could result in approximately triple the existing siltation rates in the shipping channel. Existing spatial deposition patterns for the shipping channel are illustrated in Figure 12. The highest sedimentation occurs in a one-mile segment of the dredged channel that includes the junctions of West Point Slough and Corkscrew Slough.

To avoid impacts to the shipping channel, the project must not increase the tidal prism carried through Redwood Creek above existing conditions. Hydrodynamic and cohesive sediment transport modeling results (Appendix B) indicate that when Middle or Inner Bair is breached, flow control structures are required in Smith and Corkscrew Sloughs to limit post-restoration tidal prism. The restoration alternatives include a channel constriction in Corkscrew Slough to route tidal prism from restored Middle Bair to Steinberger Slough, with little flow to Redwood Creek. To be effective, the constriction must be east of the Middle Bair breaches. Realignment of Smith Slough to its historic meander in Inner Bair serves a similar purpose, routing tidal prism from restored Middle and Inner Bair preferentially to Steinberger Slough. See Figure 2 for an illustration of the locations of the flow control structures.

Other solution approaches were considered and rejected based on modeling results. These approaches include: phasing the restoration by pond to allow Steinberger Slough to scour near Outer Bair prior to breaching Middle and Inner Bair, dredging Steinberger Slough, limiting the number and location of breaches, and using seasonal or temporary hydraulic structures/channel realignments.

5.2.4 Pete's Outer Harbor Tidal Currents and Navigation

Preliminary modeling results indicated that if Inner and Middle Bair were restored by breaching at the historic channel locations, without including any flow modifications, velocities at Pete's Outer Harbor will increase from approximately one foot per second (fps) under existing conditions to nearly three fps. Generally accepted marina design guidelines indicate that velocities above one fps pose navigation difficulties for small watercraft. Post-project velocities of up to three fps are likely to be unacceptable to the marina. This increase would likely diminish over time as it is likely that within a few years the channel would scour and widen until it reached a new equilibrium cross section with the tidal flow.

Several solutions approaches to reducing impacts to tidal velocities were considered:

- Widening Smith Slough in the vicinity of the harbor to increase the cross-sectional flow area;
- Constructing a bypass channel through Middle Bair to route flow around Pete's Outer Harbor;
- Breaching Middle Bair only along Corkscrew Slough to reduce tidal flows in Smith Slough;
- Dredging Steinberger Slough;
- Phasing restoration by pond so that Steinberger Slough scours and deepens near Outer Bair before breaching Middle and Inner Bair.
- Constricting flows from Smith and Corkscrew Sloughs to Redwood Creek, thereby directing more flow toward Steinberger Slough.

In the end, constricting flows from Smith and Corkscrew Sloughs to Redwood Creek was the only approach that avoided impacts to both the Redwood Creek shipping channel and Pete's Outer Harbor.

5.3 RESTORATION TEMPLATE DESIGN FEATURES

The site template for the tidal wetland design relies on deposition of sediments from in-flowing waters to fill the subsided sites. As sediments accumulate, natural geomorphic and biological processes will restore tidal wetland function. Dredged material may also be placed on site to accelerate the evolution process. The site template will be established prior to reintroducing tidal action, and will consist of:

- Breaches in the perimeter levees.
- Connector channels in the site interior. These channels will be excavated through interior berms to reconnect segments of historic channel.
- "Cut-off berms" to block tidal flow through the borrow ditches and promote reestablishment of the remnant natural tidal channels. Cut-off berms have been used successfully at the Cooley Landing Marsh Restoration in South San Francisco Bay.
- Excavated channel(s) on Inner Bair to allow for more rapid tidal channel formation following restoration and to connect remnant channels to the primary drainage channels.

Dredged material, if available, will be used to raise the elevation of Inner Bair Island and to construct site features, as needed.

6.0 ANALYSIS OF ALTERNATIVES

Based upon the identified existing site conditions and identified opportunities and constraints a range of restoration alternatives were prepared. A total of six restoration alternatives were prepared and described to the TRT on December 5, 2000. Due to design constraints and through further discussions with personnel from the USFWS, CDFG, and the TRT, a more limited and realistic set of alternatives were developed. These five alternatives are briefly described below. From these five alternatives, one preferred alternative will be carried through in detail to conceptual design. The following discussions assume a 50-year planning horizon, consistent with that used by other San Francisco Bay restoration projects currently in planning.

6.1 ALTERNATIVES

1. No project

For the no project alternative, we assume that USFWS would discontinue on-going levee maintenance at Middle and Outer Bair Island and would not repair any levee breaches. Minimal levee maintenance would occur on Inner Bair Island to protect the existing infrastructure. Eventually, the levees on Middle and Outer Bair will fail and will return to a tidal system. However, the time frame for habitat restoration would be greatly increased, and the timing and location of breaches could not be optimized to maximize benefits to wildlife or to minimize impacts to surrounding infrastructure.

Unmanaged tidal inundation of the Middle and Outer Bair Islands would result in an increased tidal prism that would induce greater siltation within the Redwood Creek shipping channel and higher tidal velocities at Pete's Outer Harbor.

A no project alternative is a necessary part of the environmental review process and will allow comparison of the impacts of implementing the project with those that will occur without the project. Therefore this alternative will be carried forward for further evaluation.

2. Minimal Construction Tidal Marsh Restoration

Alternative 2 maximizes the use of natural processes in the ecological recovery of Bair Island, resulting in what is expected to be the lowest cost alternative that provides for restoration of the entire available 1400-acre area.

<u>Outer and Middle Bair Island</u>. Levees will be breached at historic slough channel locations on Middle and Outer Bair Islands and borrow ditch cutoff berms will be created to prevent tidal capture by the existing borrow ditches. Interior berms and levees will be selectively lowered or removed to the extent possible. Some or all of the levees adjacent to Steinberger Slough would be left in place to provide wind-wave erosion protection for the western shoreline of Steinberger Slough.

<u>Inner Bair Island</u>. Levees will be breached at historic slough channel locations on Inner Bair Island and borrow ditch cutoff berms will be created to prevent tidal capture by the existing

borrow ditches. Fill material will be used to expand the southern levee of Inner Bair Island to adequately protect the SBSA sewer line and to create a cross-levee that protects the San Carlos Airport property on Inner Bair Island. Possible sources of fill material include material excavated from levee breaches and levee crests on all three islands, excavation of the cross-levee on Inner Bair, dredged material from Redwood Creek and imported fill.

The cost of maintaining the Inner Bair levee for public access will increase somewhat over existing conditions due to increased wind-wave erosion and tidal scour. Levees will require maintenance on the inboard and outboard sides. The restored tidal prism would induce greater siltation within the Redwood Creek shipping channel and higher tidal velocities at Pete's Outer Harbor.

From an ecological perspective, this is the most direct restoration approach and it is also the most economical. However, this approach is not feasible from an infrastructure protection perspective. It would likely induce an increased bird strike hazard, Redwood Creek shipping channel siltation, and high tidal velocities at Pete's Outer Harbor. Due to the potential design-related impacts, this alternative will not receive further evaluation.

3. Tidal Marsh Restoration (Recommended Alternative)

Alternative 3 uses dredged material, most likely from Redwood Creek, to raise the marshplain elevation at Inner Bair prior to breaching. The purpose of this approach is to reduce the amount of open water at Inner Bair and to expedite the establishment of emergent marsh. Channel modifications would be made at Smith and Corkscrew Sloughs to mitigate for potential impacts to the Redwood Creek shipping channel and Pete's Outer Harbor. Smith Slough would be realigned to its historic meander through Inner Bair. Corkscrew Slough would be blocked to the east of the Middle Bair breaches.

Dredged material, or other sources of fill, would be used to expand the southern levee of Inner Bair Island to adequately protect the SBSA sewer line and create a cross-levee that protects the San Carlos Airport property on Inner Bair Island. Levees will be breached at historic slough channel locations on Inner Bair Island and borrow ditch cutoff berms will be created to prevent tidal capture by the existing borrow ditches. Although historic slough channels and borrow ditches will be filled with dredged material, differential settlement will result in a lower elevation, and therefore channel development, in these areas. The major drawbacks of dredged material placement are high cost and somewhat impaired tidal channel development.

The restoration approach for Middle and Outer Bair is the same as described in Alternative 2.

Since this alternative meets all of the project's goals and objectives as well as meets the project's design criteria, it is the preferred alternative and will be evaluated in more detail in the following section.

4. Tidal and Managed Marsh Restoration

Alternative 4 would introduce muted tides on Inner Bair Island, allowing the reestablishment of some tidal marsh, while limiting the creation of the open water habitat that would be undesirable from a bird strike hazard perspective. In this approach, a hydraulic structure(s) (e.g., flapgates) would be installed on Inner Bair to allow tidal inundation approximately between mean tide level (the existing marshplain elevation) and mean lower low water. Existing ruderal and seasonally ponded wetland vegetation on the site would likely die back and be replaced by pickleweed and other high marsh vegetation, creating a muted tidal salt marsh. The hydraulic structure(s) would require regular maintenance.

Channel modifications would be made at Smith and Corkscrew Sloughs to mitigate for potential impacts to the Redwood Creek shipping channel and Pete's Outer Harbor. A flow restrictor would be placed in Smith Slough between the two hydraulic structures into Inner Bair Island. It would be similar to the flow restrictor being placed in Corkscrew Slough, except that the flow restrictor in Corkscrew would have a notch for water flows as well as a boat portage.

The restoration approach for Middle and Outer Bair is the same as described in Alternative 2.

This alternative meets most of the project's goals and objectives and meets the project's design criteria. Therefore this alternative will be carried forward for further evaluation.

5. No Restoration of Inner Bair

This alternative consists of no restoration to Inner Bair Island. The restoration approach for Middle and Outer Bair and channel modifications are the same as described in Alternative 4.

This alternative was not chosen for further evaluation due to the overall goal of restoring tidal marsh to as much of Bair Island as possible. Additionally, the restoration of Inner Bair would provide public outreach and educational opportunities.

6.2 RECOMMENDED RESTORATION ALTERNATIVES

This section provides more detailed descriptions of the Bair Island restoration alternatives recommended for further study by the USFWS and CDFG with input from the TRT. The following three alternatives were selected:

Alternative 1: No Project
Alternative 2: Tidal Marsh Restoration
Alternative 3: Tidal and Managed Marsh Restoration

Alternatives 2 and 3 both include the restoration of full tidal action at Middle and Outer Bair; they differ only in their treatment of Inner Bair. The following discussions assume a 50-year planning horizon, consistent with that used by other San Francisco Bay restoration projects currently in planning.

ALTERNATIVE 1: NO PROJECT

In comparing and selecting a project alternative, it is important to understand how the site is likely to evolve if no action is taken. For the no project alternative, the Refuge would discontinue on-going levee maintenance at Middle and Outer Bair Islands and would not repair any levee breaches at these locations. Levees on Middle, and Outer Bair would gradually deteriorate and eventually fail, allowing tidal action. The Refuge would cooperate with San Carlos Airport and the South Bayside System Authority allowing them to maintain the levee on Inner Bair Island that protects the existing safety zone and force main pipeline. However, only minimal maintenance would occur along the Inner Bair Island levee system.

Middle and Outer Bair would likely overtop and begin to breach within the next ten years, since average levee crest elevations on these islands are below the 10-year high-tide elevations. The breaches would erode and widen over time. The existing borrow ditches would capture much of the tidal prism and establishment of the remnant historic channels would be limited. Natural estuarine sedimentation would gradually rebuild the marshplain to elevations at which vegetation could reestablish. Increased tidal flows would scour and deepen the surrounding major sloughs.

If the Inner Bair perimeter levees were allowed to subside (i.e., if they were not maintained) the site would probably breach within the 50-year planning horizon. Minimum levee crest elevations are currently approximately 7.6 feet. Over fifty years, levee subsidence on the order of several feet and sea level rise of approximately 0.5 foot would result in levee crest elevations susceptible to overtopping in a high spring tide or storm surge. Therefore to protect infrastructure located on Inner Bair Island, levee crest elevations of approximately 7.6 feet would need to be maintained. However the trail system on Inner Bair Island would be abandoned.

Unmanaged tidal inundation of the ponds could induce greater siltation within the Redwood Creek shipping channel and higher tidal velocities at Pete's Outer Harbor.

Potential Impacts to Existing Habitats and Wildlife

Middle and Outer Bair would continue to evolve in the period before the levees breach. Habitats that are now sparse to moderate cover of pickleweed may improve somewhat in that time frame. Based on the observations of pond A-11, which has not changed substantially in the past 13 years, that improvement may be negligible (see Figure 6 in Appendix G). When the levees breach, there will be loss of existing poor to moderate quality habitat for the salt marsh harvest mouse.

It is difficult to predict the changes that may occur on Inner Bair Island w/ minimal levee maintenance over a 50 year period. Over the past 13 years, the site has become less saline, dominated by more upland grasses and forbs, and seasonally ponded bare areas have accordingly diminished. If that trend continues, then we would expect continued succession of higher elevation portions of the site toward grass and shrub mixtures, while low-lying areas would likely continue to pond.

Given that scenario, impacts to wildlife habitat include the eventual loss of these ruderal upland areas and seasonal wetlands. There are species currently classified as special status that rely on these types of habitat, and would be impacted by its loss. Examples include White-tailed Kites (*Elanus leucurus*) and Northern Harriers (*Circus cyaneus*) that nest in the vicinity and forage in the upland habitats. The impacts from the loss of these habitats apply to all the alternatives. When considering this alternative, an additional impact is the delayed timing of the site to evolve from open water to vegetated marsh. Those species that flourish in fully tidal salt marsh habitat, including the federally endangered salt marsh harvest mouse and California Clapper Rail, would benefit within the first few years from the creation of small habitat areas. Large-scale habitat benefits for these species would require upwards of 30 to 50 years.

Potential Creation of Habitat and Benefits to Wildlife

The breaching of outboard levees on Middle and Outer Bair Islands would allow tidal salt marsh to become established. These marshes would evolve over a period of decades. California Clapper Rails, salt marsh harvest mice, fisheries, and the suite of vertebrate and invertebrate species dependent on tidal marshes would benefit. Inner Bair Island levees would be maintained and no new beneficial habitats would be created.

Potential benefits to wildlife include benefits to those species that inhabit salt marsh and would benefit from its eventual restoration, including the salt marsh harvest mouse and the California Clapper Rail. The Alameda Song Sparrow, which is considered a species of special concern by the State of California, is common in the salt marshes of Bair Island and would benefit from further habitat restoration.

Inner Bair currently is at elevations between –0.6 and 1.0 NGVD, and subsided 0.8 feet in about the last 20 years. If the site continues to subside, then it may be several feet below today's elevation in 50 years. The lands are already below mean tide level and, thus with additional subsidence, would be more difficult to drain during the winter months. This would lead to increased water depths and durations in Inner Bair Island following winter storms. Large areas of open water, particularly in a protected area away from wind and waves, are particularly attractive to both shorebirds (at lowest tides) and waterfowl (when the water is deeper). Large flocks of waterbirds could pose a safety hazard for the San Carlos Airport.

ALTERNATIVE 2: TIDAL MARSH RESTORATION

Alternative 2 (the preferred alternative) restores full tidal inundation to Inner, Middle, and Outer Bair. For Middle and Outer Bair, natural estuarine sedimentation will raise the marsh plain surface to allow complete vegetation establishment over time. Restoration will include features to encourage reestablishment of the natural tidal drainage network and discourage the capture of the tidal flows by borrow ditches at these two islands.

At Inner Bair, dredged material, most likely from Redwood Creek, will be used to raise the marsh plain elevation prior to breaching. The purpose of this approach is to reduce bird strike hazards for the San Carlos Airport by reducing the amount of post-breaching open water at Inner Bair. Placement of dredged material has the additional advantage of expediting the establishment of emergent marsh. Potential drawbacks of dredged material placement are cost, and impaired tidal channel development at Inner Bair (as the existing remnant slough system may be covered). Sediment quality would need to be appropriate for wetland reuse.

Channel modifications would be made at Smith and Corkscrew Sloughs to mitigate for potential impacts to the Redwood Creek shipping channel and Pete's Outer Harbor. Smith Slough would be realigned to its historic meander through Inner Bair. Corkscrew Slough would be blocked to the east of the Middle Bair breaches.

Middle and Outer Bair Islands. Levees will be breached at selected historic slough channel locations on Middle and Outer Bair Islands, restoring natural tidal flows. Pickleweed-dominated marsh vegetation will establish quickly in selected areas already at high intertidal elevations. Natural estuarine sedimentation on the lower mudflat areas will gradually build up these areas high enough for cordgrass and pickleweed to establish. Borrow ditch cutoff berms will be created to prevent tidal capture by the existing borrow ditches, allowing the natural channel system to reestablish. Interior berms and levees will be lowered or removed where possible, creating additional tidal habitat. Levees desired for upland refuge habitat or required to protect infrastructure from wind-wave erosion would be left in place.

Based on initial ground elevations and predicted sediment supply, we expect substantial tidal marsh vegetation establishment at Outer Bair within 30 to 50 years and at Middle Bair within approximately 50 years.

Inner Bair Island. Dredged material or other sources of fill would be used to expand the southern levee of Inner Bair Island to adequately protect the SBSA sewer line and create a cross-levee that protects the San Carlos Airport property on Inner Bair Island. Levees will be breached at historic slough channel locations on Inner Bair Island and borrow ditch cutoff berms will be created to prevent tidal capture by the existing borrow ditches. Although historic slough channels and borrow ditches may be filled with dredged material, differential settlement of the dredged material will result in a lower elevation, and therefore channel development may still occur in these areas.

Fill will be used to raise ground levels on Inner Bair from current elevations of approximately 0.0 to between 2.0 and 3.0 feet NGVD, requiring between 400 and 500 thousand cubic yards of fill. This target is close to the 538 thousand cubic yards dredged from Redwood Creek during an average dredging event. Redwood Creek has been dredged eight times between 1977 and 1999, and the average annual accumulation rate is estimated to be 200 thousand cubic yards.

The area within the cross-levee system protecting the San Carlos Airport safety zone, as well as the alignment of the SBSA sewer line, will be filled with dredged material to an elevation that is above MHHW. By creating upland and transitional habitats in these areas, some of the primary constraints associated with reintroducing tidal action to Inner Bair Island are minimized. From the created upland areas, the fill material will gradually slope down to the lower elevations of the restored marsh plain. Fill elevations will be highly varied, ideally providing ample areas of transitional habitat, including upland, seasonal wetland, and supratidal wetland areas. Once the levee is breached, pickleweed and cordgrass should begin to colonize the site and some channel development will occur through natural tidal scour. Pickleweed will be seeded or planted at the higher elevations, and evaluations will be made at that time on the feasibility of active planting of the native cordgrass.

Faber Tract in East Palo Alto and part of Muzzi Marsh in Corte Madera provide examples of the type of habitat that would be created at Inner Bair Island with the addition of dredged material. Both these sites are diked and subsided former tidal marshes that have been filled with dredged material to high intertidal elevations.

Potential Impacts to Existing Habitats and Wildlife

All habitats within Inner Bair Island (aquatic, ruderal, developed, seasonal wetland and diked salt marsh) would be covered with dredged material. By filling the leveed marshplain with dredged material, any wildlife currently using the project area would be impacted. Existing habitats would be lost, as would individuals of species that occur on-site presently. Timing of the deposition of such material should be coordinated to minimize effects on nesting birds, particularly special status species like Burrowing Owls. This is true of all restoration alternatives.

Potential Creation of Habitat and Benefits to Wildlife

Once the material has settled, the perimeter of Inner Bair will be seeded or planted with S*alicornia virginica* and evaluated for potential planting with *Spartina foliosa* or other native wetland vegetation prior to being opened to tidal action. Given that the dredged material has been placed at an appropriate elevation, the site should quickly develop into a tidal salt marsh system, likely to be dominated initially by cordgrass. Transition habitat will also be present along the interior perimeter of the levees.

The benefits to wildlife included in this alternative are many. The immediate sedimentation and planting of vegetation is beneficial as it decreases the delay in vegetation colonization of the marsh. The restoration process is thus expedited and organisms that use tidal salt marsh, particularly the salt marsh harvest mouse and California Clapper Rail, will colonize Inner Bair Island more rapidly. California Clapper Rails are most abundant in extensive salt marshes dominated by cordgrass, pickleweed, and marsh gumplant associated with numerous secondary tidal channels (Harvey 1980). In addition, the area will be less attractive to waterfowl once the vegetation becomes established. Increasing the elevation of the marshplain immediately, instead of waiting for natural sedimentation, decreases the depth and duration of the pooling of water on the site. Water that is shallow (a few inches) will be less attractive to large flocks of waterfowl (particularly ducks), and thus will decrease the bird-strike hazard to the adjacent airport. However, this area will be attractive to various species of wading shorebirds, such as godwits and sandpipers, during the restoration process, as they forage in shallow water. These birds pose less of a risk to the airport due to their small mass and tendency to fly very close to the water. The presence of ponding water will attract some waterbirds, and it is not possible to go through the restoration process without waterbird use of the area. This alternative minimizes the use by those species that are most hazardous to aircraft by decreasing the depth of the water, and increasing the rate that vegetation becomes established.

ALTERNATIVE 3: TIDAL AND MANAGED MARSH RESTORATION

Alternative 3 restores full tidal inundation to Middle and Outer Bair, and creates managed wetlands at Inner Bair. This alternative allows the reestablishment of some salt marsh habitat on

Inner Bair Island, while limiting the creation of the open water habitat that would be undesirable from a bird strike hazard perspective. The restoration approach for Middle and Outer Bair is the same as described in Alternative 2.

Channel modifications would be made at Smith and Corkscrew Sloughs to mitigate for potential impacts to the Redwood Creek shipping channel and Pete's Outer Harbor. Unlike Alternative 2, most of the tidal flows along Smith Slough would be routed through a hydraulic structure in Smith Slough not through the historic meander. However, potential impacts to flood hazards would be identical to those under Tidal Marsh Alternative since the partial block along Smith Slough would be sized to convey the same amount of flood flows as the breach to Inner Bair in Alternative 2. The channel modification along Corkscrew Slough would be identical to Alternative 2.

Inner Bair Island. Hydraulic control structures would be installed on Inner Bair to allow water management of the site. These structures would allow tidal inundation between approximately MLLW and MTL (the existing marshplain elevation). A managed complex of diked salt marsh, uplands and shallow seasonal wetlands is contemplated. Rainfall would contribute to ponding on the site, and would be augmented by tidal inflows on a managed basis. Existing ruderal vegetation on the site would likely die back and be replaced by pickleweed, creating salt marsh. Existing seasonal wetlands will likely remain vegetated, while deeper channels (e.g., former sloughs and borrow ditches) will remain ponded. The main disadvantages of this alternative are the initial and the on-going costs of maintaining a managed system and that it does not meet all of the project's habitat goals (e.g., restoring tidal marsh to as much of Bair Island as possible).

Water management remains to be developed, but flexibility would allow a range of management from muted tidal to occasionally flooded. Tidal inflow to Inner Bair could occur periodically except during the highest tides, to prevent high water levels and open water ponding. Water could drain from the site as frequently as each tide cycle. The hydraulic control structure will be designed for flexibility, allowing the water level management regime to be adaptively managed in response to monitoring results. Several types of hydraulic structures could be used to achieve the desired hydrology. Slide-flap gated culverts could be left in the open position most of the time, then manually closed during high tide events to allow outflow only. Alternately, float-activated gates (such as those at Shell Marsh in Martinez) could eliminate the need for manual gate closure. Floats would mechanically close the inflow culverts when water levels in Smith Slough were high. Flashboard weirs could be used in combination with gated culverts to adjust the frequency of tidal flooding and depth of on-site ponding. Pumps may need to be installed to facilitate drainage, should unusual ponding occur. Hydraulic modeling would be used to refine the hydraulic structure design.

Regular maintenance will be required to maintain the hydraulic structures in working order. Water level control will require some form on on-going active management. Maintaining public access after breaching will require periodic levee repair.

New Chicago Marsh, a managed pickleweed marshplain in Alviso, provides an example of the type of habitat that would be created on Inner Bair under this alternative. New Chicago Marsh is a diked and deeply subsided former tidal marsh managed by the U.S. Fish & Wildlife Service for pickleweed and salt marsh harvest mouse habitat. Although pumps are used at New Chicago Marsh to drain rainwater and seepage, the use of pumps could be avoided at Inner Bair because Inner Bair is not as deeply subsided.

Potential Impacts to Existing Habitats and Wildlife

The degree of flooding at Inner Bair Island under this alternative will have to be closely monitored and adaptively managed in the first two years. Ideal muted tidal conditions will avoid significant ponding and will result in a more gradual shift from existing habitats on Inner Bair to a muted tidal marsh/managed system. As outlined in the previous alternatives, the loss of existing habitats on Inner Bair Island would be considered an impact to those wildlife species utilizing those habitats. However, those impacts would not be as abrupt under this alternative, due to the more gradual shift in habitats anticipated in a managed system.

Potential Creation of Habitat and Benefits to Wildlife

The resulting muted tidal marsh habitat may lead to an increased area that remains flooded, and a greater likelihood for the formation of small ponds surrounded by vegetation. Dominant plant species would include pickleweed (*Salicornia virginica*), interspersed with areas of open water in those areas that are currently open water (remnant slough channels and borrow ditches). This alternative will likely result in a mosaic of habitats ranging from open water, mudflats and salt marsh at the lower elevations, to seasonal wetlands and upland areas along the perimeter and at the higher elevations.

This type of habitat is ideal for waterfowl and shorebirds, as it provides smaller protected areas for birds to gather, in addition to providing shelter and foraging opportunities. The seasonal wetlands and upland areas along the perimeter provide excellent nesting habitat for many waterbirds that require areas of dry land to nest. The creation and enhancement of managed marshes is in fact used by management agencies to increase waterfowl use for hunting and conservation. Therefore, the creation of a managed wetland adjacent to the San Carlos Airport Safety Zone will have to be closely monitored and managed to avoid significantly increasing the abundance of hazardous wildlife.

This alternative would ultimately result in a diked salt marsh, and therefore would provide habitat for the salt marsh harvest mouse.

6.3 DEVELOPMENT OF PUBLIC USE ALTERNATIVES

This section contains brief descriptions of five draft public use alternatives intended to represent the range of options for public use on Inner Bair Island. These public use alternatives provide a broad range of potential uses yet are physically compatible with all of the restoration alternatives. From this pool of alternatives, three alternatives were selected that will be carried forward into the environmental review process.

ALTERNATIVE 1. NO ACTION/NO PUBLIC USE

- In the short term, limited public use consistent with protection of wildlife habitat and public safety
- In the long term, public use on Bair Island would be eliminated as the infrastructure deteriorates
- No public access to Inner, Middle, or Outer Bair Islands
- No use of motorized water vehicles permitted in Smith or Corkscrew Sloughs
- Close Refuge's Bair Island parking lot on Bair Island Road

A no project/no action alternative is required for the environmental review process. Therefore, this alternative was selected for further evaluation.

ALTERNATIVE 2. MAXIMIZE PUBLIC USE

- Full loop trail on Inner Bair and Airport levees
- Educational and interpretive signage on trail, orientation kiosks and wildlife viewing platform on Inner Bair
- Restrooms will be provided
- Hunting per regulations on Middle and Outer Bair
  - Fishing by boat in sloughs and from docks on Islands
- Pets allowed off-leash
- Unlimited boat use in sloughs
- Middle and Outer Bair open to public use on remaining levees with boat access and boat docks
- Maintain Refuge's Bair Island parking lot on Bair Island Road

Due to the high level of disturbance to wildlife and the incompatibility with some of the project's goals this alternative was not selected for further evaluation.

ALTERNATIVE 3. RESTRICTED PUBLIC USE

- Trail access will extend from the Refuge entrance at Whipple Avenue to the north around the San Carlos Airport levee
- Regulatory and interpretive signs, orientation kiosk and one viewing/environmental education platform will be provided
- Restrooms will be provided
- Fishing from boats in Corkscrew and Smith sloughs but not from land
- No pets will be allowed
- No access to Middle and Outer Bair Islands except by specific Refuge approval
- Boating will be allowed in Smith and Corkscrew Sloughs with seasonal closure to all boats, and a 5-mph speed limit/no wake zone at all times.
- Maintain Refuge's Bair Island parking lot on Bair Island Road
- Hunting of waterfowl on Middle and Outer Bair will be permitted per federal, state and local regulations

This alternative will be carried forward for further evaluation.

ALTERNATIVE 4. MODERATE PUBLIC USE

- Trail access will extend from the Refuge entrance at Whipple Avenue to the north around the San Carlos Airport levee and to an observation point on Smith Slough and to the south towards Pete's Harbor to an observation point on Smith Slough
- Regulatory and interpretive signs, orientation kiosk and viewing/environmental education platform will be provided at each end of the trail at Smith Slough
- Restrooms will be provided
- Fishing from boats in Corkscrew and Smith sloughs but not from land
- Pets (dogs only) will be allowed on a 6-foot leash on designated trails for a test period of 3 months
- Public access would only be allowed on Middle and Outer Bair Islands by Refuge-guided trips and by boat to a viewing platform on Middle Bair at the flow restrictor on Corkscrew Slough
- Boating will be allowed in Smith and Corkscrew Sloughs with a 5-mph speed limit/ no wake zone at all times
- Maintain Refuge's Bair Island parking lot on Bair Island Road
- Hunting of waterfowl on Outer Bair will be permitted per federal, state, and local regulations

This is the preferred alternative. This alternative will be carried forward for further evaluation.

ALTERNATIVE 5. MODERATE PUBLIC USE/NO PETS

- Trail access will extend from the Refuge entrance at Whipple Avenue to the north around the San Carlos Airport levee and to an observation point on Smith Slough and to the south towards Pete's Harbor to an observation point on Smith Slough
- Regulatory and interpretive signs, orientation kiosk and viewing/environmental education platform will be provided
- Restrooms will be provided
- Fishing from boats in Corkscrew and Smith sloughs but not from land
- No pets will be allowed
- Public access would only be allowed on Middle and Outer Bair Islands by Refuge-guided trips and by boat to a viewing platform on Middle Bair at the flow restrictor on Corkscrew Slough.
- Boating will be allowed in Smith and Corkscrew Sloughs with restricted access areas close to shore and a 5-mph speed limit at all times.
- Maintain Refuge's Bair Island parking lot on Bair Island Road
- Hunting of waterfowl on Outer Bair will be permitted per federal, state, and local regulations

This alternative was not selected and will not receive further evaluation.

6.4 RECOMMENDED PUBLIC USE ALTERNATIVES

Below are the modified public use alternatives that will be carried through the environmental review process. The Refuge and the TRT determined that these alternatives provide the most appropriate balance of public uses and natural resources protection on Bair Island.

ALTERNATIVE 1: NO ACTION

In the short term (approximately 5 years), this alternative will allow limited public use consistent with protection of wildlife habitat and public safety. In the long term, the Refuge would eliminate public use on Bair Island as the infrastructure deteriorates (trails, signs, gates, levees, etc.) that would require additional action or maintenance for public access by the Refuge. No public access to Inner, Middle, or Outer Bair Islands will be allowed in the long term. Boating will be allowed in Smith and Corkscrew Sloughs, however it may become difficult over time as the levees degrade along the slough channels. Although levees on Inner Bair Island would require some routine maintenance, the trail system would not be maintained. Therefore, after approximately five years, no trails will be accessible to the public.

In the short term, pets (dogs only) will be allowed on Inner Bair Island on a 6-foot leash and on designated trails for a test period of 3 months to determine the compliance with Refuge public use regulations concerning dog access. In the long term, pets will be prohibited on Bair Island as the infrastructure deteriorates. The Refuge's Bair Island parking lot on Bair Island Road will be closed. No additional infrastructure (e.g., kiosks) will be constructed.

ALTERNATIVE 2: RESTRICTED PUBLIC ACCESS

Public Access will be allowed only on Outer and Middle Bair Island by Refuge guided trips and other specific exceptions that are approved by a Refuge Special Use Permit as well as to a single viewing platform located on Middle Bair Island. This viewing platform will only be accessible by boat. Access on Inner Bair Island will be allowed along a portion of the existing 3-mile loop trail located on the existing levee. Public Access will extend from the Refuge entrance at Whipple Avenue to the north around the San Carlos Airport levee and to an observation point on with a wildlife viewing platform on Smith Slough near a levee break. No access will be allowed on the levee trail to the South towards Pete's Harbor. Sanitary facilities will be provided. No pets will be allowed on Inner Bair Island. Jogging and bicycling will be permitted.

Fishing from boats in Corkscrew and Smith Sloughs will be allowed however fishing will not be permitted from land. Hunting of waterfowl on Outer and Middle Bair Islands will be allowed per federal, state and city regulations. Boating will be permitted with a speed limit of "no wake zone, maximum 5 mph for motorized water vehicles" and in Smith and Corkscrew Sloughs. No motorized vehicle access will be allowed within areas currently inside the exiting levee. Seasonal closures to all boat access will be implemented to protect sensitive species (i.e., harbor seals).

An orientation kiosk and a viewing/environmental education platform will be provided. Regulatory and interpretive signs will be located at the orientation kiosk. The Refuge's Bair Island parking lot on Bair Island Road will be maintained.

ALTERNATIVE 3: MODERATE PUBLIC ACCESS (RECOMMENDED ALTERNATIVE)

Public Access will be allowed only on Outer and Middle Bair Island by Refuge guided trips and other specific exceptions that are approved by a Refuge Special Use Permit as well as to a single viewing platform located on Middle Bair Island. This viewing platform will only be accessible by boat. Access on Inner Bair Island will be allowed along an extensive portion of the existing 3-mile loop trail located on the existing levee. Public Access will extend from the Refuge entrance at Whipple Avenue to the north around the San Carlos Airport levee and to an observation point on Smith Slough near a levee break. Access will also be allowed on the levee trail to the South towards Pete's Harbor to an observation point on Smith Slough near a levee break. Sanitary facilities will be provided. Pets (dogs only) will be allowed on Inner Bair Island on a 6-foot leash and on designated trails for a test period of 3 months to determine compliance with Refuge public use regulations concerning dog access (see Appendix D for the proposed Dog Use Monitoring Program). Jogging and bicycling will be permitted.

Fishing from boats in Corkscrew and Smith Sloughs will be allowed, however fishing will not be permitted from land. Hunting of waterfowl on Outer and Middle Bair Islands will be allowed per federal, state and city regulations. Boating will be permitted with speed limits of "no wake zone, maximum 5 mph for motorized water vehicles" in Smith and Corkscrew Slough. No motorized vehicle access will be allowed within areas currently inside the exiting levee.

An orientation kiosk and two viewing/environmental education platforms at each end of Inner Bair Island trail at Smith Slough will be provided. Regulatory and interpretive signs will be located at the orientation kiosk. The Refuge's Bair Island parking lot on Bair Island Road will be maintained.

Access (both on trail and by boat) has been limited in this recommended alternative to protect sensitive wildlife species at Bair Island. This is based upon a large volume of research conducted on the effects of various recreational activities on wildlife. Recreation is becoming more of a concern as human use of wild areas increases, and the size of those areas decreases. Thus, humans and wildlife are more and more likely to come into contact.

Waterbirds, both shorebirds and waterfowl, vary dramatically according to species in how they react to human presence. During the non-breeding season, birds such as mallards and gulls tend to have a relatively high threshold of disturbance. However, during the breeding season most wildlife is very protective of nests and offspring, and their tolerance to disturbance drops. Even during the non-breeding season, disturbance may have an equally detrimental effect on the animals although not as obvious an effect. It has been demonstrated that human activity in wild areas is correlated with declines of breeding populations in birds (Knight and Gutzwiller 1995).

Activities involving rapid movement and loud noise (e.g., power-boating, water skiing) have been found to rank the highest in level of disturbance to waterbirds (Mathews 1982). Some documented impacts of motorboats include shoreline degradation, disruption of nesting and feeding resulting in a loss of production, as well as displacement of birds. Not only can the noise be a disturbance and cause a bird to flush, but the bow waves can tip over exposed nests. Motorboats can flush waterbirds and interrupt feeding for a much longer period than can quieter, slower activities (such as canoeing and kayaking). Therefore, to decrease the level of disturbance, all motorized vehicles (i.e., motorboats, personal water crafts, jet boats and hovercrafts) will be subject to speed limits of “no wake zone, maximum 5 mph for motorized water vehicles” in Smith and Corkscrew Sloughs. No motorized vehicles will be allowed within areas currently inside the exiting levee.

6.5 SUMMARY

Through a series of meetings, the Refuge staff, the CDFG and the TRT reviewed the Draft Restoration and Public Use Alternatives. From these meeting, modifications were made to the Draft Alternatives and a consensus was reached on the Alternatives outlined below.

RECOMMENDED RESTORATION ALTERNATIVES:

Alternative 1: No Project
Alternative 2: Tidal Marsh Restoration
Alternative 3: Tidal and Managed Marsh Restoration

RECOMMENDED PUBLIC USE ALTERNATIVES:

Alternative 1: No Action/No Public Use
Alternative 2: Restricted Public Access
Alternative 3: Moderate Public Access

7.0 PREFERRED ALTERNATIVE

7.1 INTRODUCTION

The Tidal Marsh Restoration is the preferred alternative design based upon its ability to maximize the potential for the restoration of tidal salt marsh habitat over most of the project area and provide protection for the infrastructure located on or adjacent to Inner Bair Island. This design meets all of the project's goals and objectives and provides the best opportunity for maximizing the desired ecological functions of the site.

Based upon the geomorphic approach to wetland restoration design, it is anticipated that habitat and ecological functions of the site will gradually change over time. Tidal salt marsh habitat will eventually become the dominant, long-term habitat type on Bair Island. However, Middle and Outer Bair will initially consist of subtidal and intertidal habitats. The use of dredged material and planting on Inner Bair Island will expedite the development of emergent tidal marsh, it is anticipated that initially the site will be rapidly colonized by wetland vegetation.

This section describes expected habitat evolution (Section 7.2), conceptual restoration design and design features (Section 7.3), infrastructure protection (Section 7.4), public use features (Section 7.5), dredged material placement (Section 7.6), phasing/breach timing (Section 7.7), anticipated construction methods (Section 7.8), and preliminary cost estimates for implementing the restoration project (Section 7.9).

7.2 EXPECTED HABITATS AND SITE EVOLUTION

After restoration, Inner, Middle, and Outer Bair are expected to evolve from predominantly tidal mudflat to tidal salt marsh habitat. Inner Bair is expected to colonize rapidly with wetland vegetation (including cordgrass), with substantial areas of vegetated marsh developing within the first 5 to 10 years on the dredged material fill. Dredged material will be used also to create areas of upland habitat and extended transitional zones between tidal marsh and upland habitats. Pickleweed will be present along the fringes of the levees and the lower elevations of the transition zone. The establishment of pickleweed-dominated marsh on Inner Bair will require an additional 10 to 15 years.

Colonization of emergent marsh vegetation at Middle and Outer Bair, which will initially be lower in elevation than Inner Bair (after dredged material is placed), will take longer. Initially following breaching, the ground elevations will generally be too low in the tidal frame for marsh plants to establish or survive at Middle or Outer Bair. Upland habitat will remain on the existing levee system. The site will be predominately intertidal mudflats with areas of cordgrass. Pickleweed will begin to colonize areas along the interior and perimeter levees. Sediments will gradually accumulate and raise the mudflats of Middle and Outer Bair to intertidal elevations that can be colonized by cordgrass. Later, as sediment continues to build, plant species typically found in 'high marsh' areas such as pickleweed, saltgrass and gumplant will establish.

Based on initial marshplain elevations and suspended sediment supply, we expect significant marsh colonization to occur at Outer Bair within approximately 10 to 50 years, and at Middle Bair within approximately 50 years. Evolution rates will be slower for Middle Bair because it is further from the Bay and the supply of suspended sediment at Middle Bair (25 to 50 mg/l) will be lower than at Outer Bair (50 to 75 mg/l). These evolution estimates are based on long term sedimentation modeling and empirical data from other restored San Francisco Bay tidal marshes (Figure 8). The long-term sedimentation modeling of the number of years required to raise average ground elevations from 1 to 2 ft NGVD (Figure 14 and Appendix C) probably overestimates the time for initial vegetation establishment because it uses average site elevations and does not account for spatial distributions in sediment deposition. In reality, the marshplains are characterized by slight variations in topography and some areas that are initially higher in elevation, such as near the breaches and channel edges, will vegetate more quickly. Also, spatial variations in sedimentation will result in localized areas of vegetated marsh nearest the breaches, where sediments will deposit most rapidly.

Although wind wave action can delay site evolution, features incorporated into the design at least partially offset this type of potential delay. At Inner Bair, filling the site allows vegetation to colonize rapidly, providing resistance to wave erosion. At Outer Bair, wind wave delays are expected to be offset by a relatively high sediment supply. At Middle Bair, the interior levees will be left in place to provide some sheltering benefits. Based on the successful site evolution of Outer Bair Ponds B1 and B2, it is our opinion that Middle and Outer Bair can be successfully restored by reintroducing tidal action. Ponds B1 and B2 are former salt production ponds on Outer Bair that are now restored to tidal marsh (see Appendix F, Figure 6 for exact locations). Middle and Outer Bair are similar to Ponds B1 and B2 in terms of wind fetch and initial site elevation (Figure 13).

The antecedent tidal channels, which are likely filled with somewhat consolidated sediments, are expected to scour and deepen once the ponds are breached. Scour is expected to occur first nearest the breaches, gradually headcutting back into the pond interiors.

Because Steinberger Slough and parts of Smith and Corkscrew Sloughs are initially undersized relative to the large restored tidal prism, tidal damping is predicted in the slough channels and ponds early in site evolution. Modeling of initial restored conditions indicates that low tide drainage in the three ponds is limited to a few tenths of a foot below mean tide level (approximately 0 ft NGVD). In Inner Bair, this is 2 to 3 feet below the initial fill elevation. Therefore, Inner Bair Island will drain adequately during low tides. However, in Middle and Outer Bair, low tide drainage is approximately one foot below the average marshplain elevation. The damping of low tide drainage may somewhat inhibit vegetative growth in areas due to more stressful biogeochemical conditions associated with a greater depth and duration of flooding. Damping may also delay the reestablishment of the antecedent tidal channels inside the ponds. As the slough channels scour and enlarge over time, however, low tide drainage will improve. Damping is expected to be a transitory effect.

The expected habitats at 50 years after construction and their importance to wildlife at Bair Island are discussed below (Figure 4):

Tidal Salt Marsh. Cordgrass (*Spartina foliosa*) will be the dominant plant species in the low marsh while pickleweed (*Salicornia virginica*) will be the dominant plant species within the middle marsh. A mix of salt marsh plant species including saltgrass (*Distichlis spicata*), pickleweed, alkali heath (*Frankenia salina*), jaumea (*Jaumea carnosa*), perennial peppergrass (*Lepidium latifolium*), gumplant (*Grindelia* sp.) and spearscale (*Atriplex triangularis*) is expected in the high marsh.

Potential benefits to wildlife include benefits to those species that inhabit salt marsh and would benefit from its eventual restoration, including the salt marsh harvest mouse and the California Clapper Rail. These two species are completely dependent on salt marsh for habitat, and their numbers would likely increase as a result of the restoration of salt marsh. The Alameda Song Sparrow, which is considered a species of special concern by the State of California, is common in the salt marshes of Bair Island and would also benefit from further habitat restoration. In addition, many other species of waterbirds and shorebirds that use this habitat for foraging and nesting would benefit, including Great Blue Herons, Great Egrets, Snowy Egrets, Black-crowned Night Herons, Forster's Terns, Willets, and other shorebirds.

Channels and Subtidal Zone. Channels are entirely unvegetated and are typically imbedded within tidal marshes and vary in width and depth. Many species of shorebirds will move into the tidal channels to forage in the mud during low tide, much like they will on the mudflats. These birds include the Long-billed Curlew (*Numenius americanus*), American Avocet (*Recurvirostra americana*), and the Black-necked Stilt (*Himantopus mexicanus*).

Tidal Mudflats. Tidal mudflats are typically inundated twice daily and located adjacent to tidal marshes at the edge of the bay or slough channels. Tidal mudflats are not vegetated by emergent plant species.

Tidal mudflats provide important foraging habitat to a number of wildlife species, particularly shorebirds. Many birds will only forage on mudflats, roosting elsewhere during high tides. These birds include the Semipalmated Plovers (*Charadrius semipalmatus*), Marbled Godwits (*Limosa fedoa*), and sandpipers (*Calidris sp.*). Numerous species of gulls also feed on invertebrates that are exposed on mudflats during low tides, including Bonaparte's Gulls (*Larus Philadelphia*), Ring-billed Gulls (*Larus delawarensis*), and California Gulls (*Larus californicus*).

Upland/Transition Zone. These habitats are typically located on the periphery of tidal salt marshes or occur as levees and are imbedded within the tidal marsh/channel complex. Upland areas adjacent to tidal marshes in San Francisco Bay are typically dominated by herbaceous non-native plant species such as perennial peppergrass, sweet fennel (*Foeniculum vulgare*), black mustard (*Brassica nigra*), wild radish (*Raphanus sativus*) and ice plant (*Carpobrotus edulis*). Other species expected to occur in the transition zones include gumplant, saltgrass and alkali heath. The transition zones between upland and salt marsh provide habitat for several special status plant species, including marsh gumplant (*Grindelia stricta* var. *angustifolia*) and Point Reyes bird's-beak (*Cordylanthus maritimus* ssp. *palustris*).

Though upland areas are not considered critical habitat, they provide crucial refuge and foraging opportunities for both birds and mammals. Many raptor species, such as the White-tailed Kite and Northern Harrier, will regularly forage for small mammals in upland areas. During high tide, many mammals and birds may seek refuge along the edge of the marsh and on the levees, including small mammals and many shorebirds that are waiting out the high tide to continue foraging. Unfortunately, non-native predators such as feral cats and red fox use these areas for cover as they are hunting native wildlife.

A design that will prepare the site for the passive restoration of these habitats on Bair Island is the goal of this alternative.

7.2.1 Non-native Cordgrass (*Spartina alterniflora*) Control

Background. San Francisco Bay contains a native species of cordgrass, Pacific cordgrass (*Spartina foliosa*). The growth of Pacific cordgrass is restricted to the upper intertidal fringes of the Bay's estuaries leaving the mid and lower intertidal mudflats devoid of vegetation (Daehler & Strong 1996). In contrast, smooth cordgrass (*Spartina alterniflora*), a dominant species of Eastern U.S. coastal marshes, is a perennial saltmarsh grass that was introduced to the San Francisco Bay in the 1970's. Since its introduction, smooth cordgrass has invaded low tidal marsh and open mudflats (Grossinger *et al.* 1998). Recent studies have shown that the native cordgrass and introduced smooth cordgrass readily hybridize. Hybridization proceeds in both directions with hybrid plants containing either smooth cordgrass or Pacific cordgrass halotypes (Anttila et al. 2000). Furthermore, it is assumed that there is a very high potential for these hybrids to outcompete Pacific cordgrass both ecologically and genetically within the Bay Area. Therefore, the spread of the hybrid species to other marshes in California could be more threatening to the native species than the initial introductions of smooth cordgrass (Anttila et al. 2000).

The invasion of smooth cordgrass and its hybrid throughout San Francisco Bay has affected, and will continue to affect, the ecology of the Bay in several ways. In some areas open mudflat habitat has been converted to smooth cordgrass meadow. In other areas (i.e., the mouth of Alameda Creek) smooth cordgrass and/or hybrids appear to be encroaching into higher elevation areas currently dominated by pickleweed (*Salicornia virginica*). Research regarding the ecological effects of smooth cordgrass on Bay Area fish and wildlife is still in the early stages. However, studies of benthic invertebrates have shown that buried deposit feeders and predators were at a higher density in smooth cordgrass stands and surface deposit feeders were at a higher density in mudflat habitat (Cordell et al, unpublished conference proceedings 1998). The degree of smooth cordgrass colonization also affects the overall density and trophic character of the benthic macroinvertbrate assemblage (Luiting et al, unpublished conference proceedings 1997). These documented differences in diversity and availability of benthic invertebrate prey resources between uncolonized mudflats and areas of smooth cordgrass may negatively impact larger consumers that feed primarily on the littoral mudflats.

The growth of cordgrass, including the native Pacific cordgrass, introduced smooth cordgrass and hybrids, decreases the rate of tidal flow, causing suspended sediment to precipitate, while dense root mats trap sediment creating a depositional environment. Therefore, the presence of cordgrass can increase sedimentation creating a positive feedback scenario in which these plants increasing the elevation of the microtopography around them thereby reducing the tidal influence on their growth and recruitment.

The California State Coastal Conservancy and the U.S Fish and Wildlife Service are currently finalizing a Programmatic Environmental Impact Statement (EIS)/ Environmental Impact Report (EIR) for the San Francisco Estuary Invasive *Spartina* Control Program (SFEISCP 2002). This control program will address the management and eradication of four non-native *Spartina* species in the bay area. The Coastal Conservancy has determined that 469 acres of San Francisco Bay are currently dominated by the invasive smooth cordgrass and its hybrids (SFEISPC 2002). It is also predicted that the hybrid cordgrass is poised to convert 10,000 to 30,000 acres of unvegetated tidal flats to *Spartina* meadows (ISP 2002). Given the proximity of non-native *Spartina* to the project site, it is likely that some colonization of this invasive species will occur after tidal influence is restored.

Colonization Predictions. Daehler and Strong (1996) predicted the extent (acreage) of invasion by smooth cordgrass in Bodega Harbour, CA (currently no smooth cordgrass is found in this harbour) using relationships between mean tidal range, and growth range of smooth cordgrass on the Atlantic coast (McKee & Patrick 1998). Following the methods outlined by Daehler and Strong (1996) a calculation based on the tide characteristics at Redwood Creek, channel marker No. 8 (Table 1) revealed that the upper threshold of smooth cordgrass growth on Bair Island would be +0.36 ft NGVD. Based on field data and calculations at the project site this upper threshold elevation of +0.36 ft NGVD seems to be too low, with cordgrass growing at a mean elevation of +1 to 2 ft NGVD.

McKee and Patrick's findings (1988) therefore, appear to be inapplicable to the growth elevation of smooth cordgrass on Bair Island. A potential explanation for this is the difference between conditions of the San Francisco Bay and the Atlantic and Gulf of Mexico coasts (i.e., smaller tidal ranges, multiple plant stressors, soil temperature, salinity, presence of predators, competition between plant species) where the relationship between mean tidal range and growth range were first described.

Of interest is the fact that smooth cordgrass is capable of vigorous growth across the entire marsh elevations in its native habitat and appears to be excluded from high-marsh habitats by competition with high-marsh perennials (Bertness & Ellison 1987 and Bertness 1991). Research in New England marshes has also shown that smooth cordgrass is an early colonizer following disturbance and is often displaced by better competitors as time passes (Bertness 1991). Therefore interspecies competition in the San Francisco Bay may influence the elevational range of smooth cordgrass in concert with mean tidal ranges.

It should be assumed that the invasion of smooth cordgrass on Bair Island will vary in extent over time. Initially mudflats on Bair Island will provide a suitable opportunity for the invasion of smooth cordgrass and will require management. However, as native vegetation establishment progresses and sediment is deposited opportunities for smooth cordgrass propagules will vary spatially throughout the restoration site making the predictions for colonization of the invasive cordgrass on Bair Island very complex. For this reason we propose a variety of control methods be adaptively implemented as the restoration site conditions change over time (see Smooth cordgrass control plan for Bair Island below).

Species Identification. The control of smooth cordgrass in San Francisco Bay is complicated by the fact that field identification of the species is very difficult. Many professional botanists have resorted to genetic testing to differentiate between smooth cordgrass, Pacific cordgrass and the hybrids. For this reason, prior to any smooth cordgrass control or eradication program representative samples of individuals within the area to be treated should be sent for genetic testing. The ISP has resources available for carrying out the genetic testing and may be contacted whenever identification of the species is indiscernible (Contact: Katy Zaremba, Invasive Spartina Project, California Coastal Conservancy at 510-286-4091).

Smooth cordgrass has also evolved a new ecotype in San Francisco Bay (Daehler et al. 1999). A dwarf ecotype with one-fifth the tiller height, tenfold the tiller density and is restricted to growth in the upper zone can be found in San Francisco Bay. The ecological range of the dwarf smooth cordgrass ecotype is similar to that of *Spartina patens*, a dominant plant species of higher elevation salt marshes of the Atlantic and Gulf coasts. Daehler et al (1999), suggest that the absence of *S. patens* from most of San Francisco Bay has allowed the dwarf ecotype of smooth cordgrass to survive and spread.

Potential Non-target Impacts of Smooth Cordgrass Control. The California Clapper Rail *(Rallus longirostris obsoletus)* is a Federal Endangered Species (*Federal Register* 35:1604; October 13, 1970). In south and central San Francisco Bay clapper rails typically inhabit salt marshes dominated by pickleweed and Pacific cordgrass. Although opinions vary on the use of smooth cordgrass habitat by the California Clapper Rail, this species will have to be considered during the planning and implementation of smooth cordgrass control. The California Clapper Rail breeding season extends from February 1 through August 31 in the Bay Area.

As mentioned above, the determination of cordgrass species in the field can be very challenging. For this reason the unintentional removal of the native Pacific cordgrass could be a non-target impact of smooth cordgrass control. Throughout the implementation of a smooth cordgrass control plan on Bair Island genetic testing will be used if the species of cordgrass recruiting within the restoration site is unclear.

Summary of Potential Methods to Control Smooth Cordgrass. Table 3 summarizes a variety of *Spartina* sp. control methods that have been applied in New Zealand, Washington State and the San Francisco Bay Area. These methods may vary from those outlined for use in the San Francisco Estuary Invasive *Spartina* Control Program (SFEISCP 2002).

Table 3. Summary of Potential Methods to Control Smooth Cordgrass

Control Method	Appropriate Setting	Timing	Effectiveness in New Zealand (Shaw & Gosling 1997)	Effectiveness in Willapa Bay, WA (Norman & Patten 1997, Grevstad, 2002)	Effectiveness in San Francisco Bay, CA (ISP 2002)	Applicability to Bair Island
Hand pulling and digging	Seedlings in newly infested areas and small areas (less than 1 acre) of infestation.	Seedling hand removal best done in spring	Not applied in this study	Applied to 1-3 year old clones 97 to 100% effective	If all rhizomes are removed 100% effective	Applicable in areas of new infestation where accessibility permits
Clipping seedheads to prevent pollination and seed dispersal	Isolated clones or small areas where prevention of pollen and seed dispersal will prevent hybridization with native *Spartina.*	Before maturation of seeds in the fall.	Not applied in this study	Not applied in this study	All seeds collected will be prevented from germinating. Not suitable for areas of high infestation.	Undesirable method due to presence of smooth cordgrass throughout the South Bay.
Mechanical smothering and burial	Large areas with machine access	During fall and winter. As close to the period of dormancy as possible	Not applied in this study	Not applied in this study.	No information available	Undesirable due to the redisturbance of channels and native vegetation.
Mechanical ripping of root mass	Meadows and large areas	Any time of year, however facilitated by winter dieback	Not applied in this study	Not applied in this study. However, is reportedly working in Washington	No information available	Undesirable due to the redisturbance of channels and native vegetation.
Biological control with *Planthopper Prokelisia marginata*	Large areas	Any time of year	Not applied in this study	50% reduction in 3 months after introduction	*Planthopper* is known to be present in San Francisco Bay (Strong and Daehler 1955)	Smooth cordgrass in San Francisco Bay likely already exposed, therefore Planthopper could not be introduced.

Control Method	Appropriate Setting	Timing	Effectiveness in New Zealand (Shaw & Gosling 1997)	Effectiveness in Willapa Bay, WA (Norman & Patten 1997, Grevstad, 2002)	Effectiveness in San Francisco Bay, CA (ISP 2002)	Applicability to Bair Island
Mowing	Any size infestation except seedlings	Any time of year, however facilitated by winter dieback. Requires 8-12 repetitions	Not applied in this study	95% kill (average of 2, 3 and 4 mowing regimes)	Multiple mowings are necessary.	Longer growing season in California may make mowing more labor intensive.
Covering	Small to medium size areas with reduced tidal influence to avoid dislodgement	Any time of year, however facilitated by low growth form in the spring	Not applied in this study	Not applied in this study	Successful in patches up to 36-feet in diameter.	Accessibility and sediment making removal of cover material difficult.
Application of glyphosate	Any size infestation	Most effective when plants are flowering or soon after	Was determined to be ineffective at one study site	81% (spray) to 91% (hand wipe) effective	Ranging from 0 to 100% depending on timing relative to plant dormancy, inundation, weather conditions etc.	Applicable if herbicide can be applied from July-August.
Application of haloxyfop-ethoxyethyl ester at 100g/l	Any size infestation	Information not available	This was determined to be the most effective method throughout New Zealand	Not applied in this study	No information available	May harm fish species, therefore unsuitable.

7.2.2 Smooth Cordgrass Control Plan for Bair Island

Efforts throughout San Francisco Bay. As mentioned above, the California State Coastal Conservancy has released the draft EIS/EIR outlining a bay wide control plan for four invasive species of *Spartina*. The following recommended controls for smooth cordgrass within the Bair Island restoration site follows many of the suggestions and methods contained within the bay wide preferred alternative (SFEISCP 2002). If necessary the control methods listed below should be modified to remain consistent with the final approved version of the San Francisco Estuary Invasive *Spartina* Control Program EIS/EIR.

Existing Colonies. The control of smooth cordgrass (including hybrids) on Bair Island will begin prior to the reintroduction of tidal influence. Existing colonies of smooth cordgrass within the restoration site, as well as colonies that are determined as a potential propagule source for vulnerable areas within the restoration site, will be treated with a hand application of a mixture of 4.0 to 5.0% Aquamaster (active ingredient glyphosate) and 0.5 to 1.0% of an EPA approved surfactant for use in aquatic habitats (i.e., Agridex, R-11 or LI-700). A dye (preferably "Blazon Blue Spray Pattern") should also be included in the mixture so that crews know where the herbicide has been applied. The application of herbicides on these existing colonies will be timed to maximize the exposure of the plants to sunlight, reduce exposure to high winds (above 5-10 mph), minimize chances of expected rains within 5 to 6 hours of application, and allow for at least six hours of air exposure during low tide.

Based on research in Willapa Bay, the application of glyphosate using a hand wipe could be the most cost effective method of treatment. This recommendation is based on the fact that the percent kill was slightly higher (91% vs. 81%) and the cost lower ($310/acre vs. $585/acre) when compared to hand spraying (Norman & Patten, unpublished conference proceedings 1997). The application of herbicides will be carried out on an annual basis for three consecutive years using a method that completely covers the plant surface such as a spray or wipe and preferably started at least two years prior to the introduction of tides on Bair Island. The methods that will be used will conform with those outlined in the San Francisco Estuary Invasive Spartina Control Program.

Although measures will be required to protect the California Clapper Rail, the herbicides should be applied when smooth cordgrass colonies are flowering in June-August. However, the Refuge has had success in treatment through September and into early October. If permitting constraints and/or other reasons do not allow for the application of glyphosate until September 1st – January 31st, the smooth cordgrass will be entering its dormant period and the application of glyphosate will likely be less effective. In this scenario, herbicide application may not be the best resource allocation. Consideration should be given to the redirection of resources to preventing new infestations and/or hybridization with native cordgrass (see maintaining open mudflat habitat and adaptive management below).

Maintaining Open Mudflat Habitat. Approximately one year prior to the restoration of tidal influence on Inner Bair Island, dredged material will be placed in Inner Bair Island. Native wetland vegetation will be planted where feasible in this area (see Planting Plan below) in an effort to reduce the area available to smooth cordgrass recruits. In addition to this planting, newly recruiting smooth cordgrass will be hand pulled and any established non-native cordgrass in close proximity will have seed heads removed to prevent hybridization. Cost-efficacy of hand pulling is lower in the late spring vs. mid-summer (4 cents/stem vs. 12 cents/stem). Unlike herbicide treatment the percent kill is close to 100% (if all rhizomes are removed), regardless of treatment timing (Norman & Patten, unpublished conference proceedings 1997). Therefore, although spring treatment is recommended this type of control can be implemented outside of the clapper rail breading season.

Hand pulling of new smooth cordgrass and hybrid recruits (or herbicide application if this method is chosen) within all of Bair Island will be carried out annually for three years after tidal influence is restored.

Initially it seems logical to set a percentage goal for open mudflat habitat within the Bair Island restoration site (i.e., prior to 1880 it is estimated that 27% of the baylands were open tidal flat habitat – reference: South Bay Subregion in Goals Project 1999). However, because the desired restoration alternative is to allow natural sedimentation and channelization to drive the creation of habitat on Bair Island the elevation of restored areas will not remain consistent over time and opportunities for smooth cordgrass will shift both temporally and spatially. An adaptive management approach will allow the control of smooth cordgrass to focus on maintaining open mudflats at a suitable elevation, and reduce the spread of smooth cordgrass into areas where it will threaten the native vegetation.

Adaptive Management. As part of the Invasive *Spartina* Control Program, smooth cordgrass will be controlled for 2-3 years prior to the first breach in Outer Bair Island at OB1. Three years after tidal influence has been restored to any portion of Bair Island, the extent of smooth cordgrass infestation will be reevaluated and the challenge and feasibility of controlling the introduced cordgrass will be reassessed in relation to conditions in the South Bay and regional efforts of smooth cordgrass control. At this time it may be deemed infeasible to eradicate the invasive species in perpetuity. If this is the case, control may focus on limiting the smooth cordgrass growth to a specific elevation to maintain areas of open mudflat and insure that it is not encroaching on higher marsh habitat.

7.2.3 Planting Plan

Planting of native vegetation is recommended at Inner Bair Island (for bird strike minimization). This revegetation opportunity is afforded by the fact that dredged material will be used on Inner Bair Island to raise the marsh plain elevation to a level appropriate for the immediate establishment of emergent salt marsh. This opportunity only exists on Inner Bair, as we are relying on natural sedimentation processes to restore the marsh plain elevation on Middle and Outer Bair Island.

Planting native vegetation will expedite the development of emergent tidal salt marsh habitat on Inner Bair Island. This will also give the native species a foothold on Inner Bair and help to minimize colonization by the non-native species. It is likely that pickleweed or other wetland starter plantings will be installed at the appropriate elevations around the project perimeter. Planting native cordgrass on Inner Bair Island will depend on the success of the eradication of smooth cordgrass on Outer Bair Island and other nearby sources. If smooth cordgrass is still growing nearby, no cordgrass will be planted to help facilitate the eradication efforts of the Invasive *Spartina* Control Program.

Inner Bair Island will be planted with native species contract grown from propagules collected from the South Bay and genetically tested to verify species. Plantings will be installed between November 1 and January 30 immediately prior to levee breaching and the restoration of tidal influence. It is likely that portions of Inner Bair cannot be planted due to the unconsolidated nature of the dredged material, which would hamper access to the site's interior. Holes approximately 12 inches wide and 18 inches deep will be dug for the plantings, and they will be installed so that their root crowns are even with the soil surface. All plantings will be irrigated immediately following installation.

Plant Procurement. Container plants will be contract grown. The propagules will be collected from the Bair Island complex or nearby salt marshes in South San Francisco Bay, preferably salvaged from the tidal wetland areas to be impacted by the levee breaches. After plant propagules/plugs, are collected, 6-12 months of growing time is generally required before the plants are ready for installation.

7.3 RESTORATION DESIGN FEATURES

The design includes the following features intended to promote tidal marsh evolution: breaches, channel connectors, borrow ditch cut-off berms, and levee lowering.

- <u>Breaches:</u> Excavations through perimeter levees that open the site to tidal action from surrounding sloughs,
- <u>Channel Connectors:</u> Excavations through internal levees that reestablish some part of the drainage network internally,
- <u>Borrow ditch cut-off berms:</u> Excavated material from breach creation placed on site to block and partially fill borrow ditches, and
- <u>Levee lowering:</u> certain segments of levees that will be lowered to generate fill material for construction of the cut-off berms.
- <u>Channel flow control structures:</u> Flow control structures will be utilized on Smith Slough and Corkscrew Slough to encourage scour of Steinberger Slough, and to prevent increases in flow velocity at Pete's Harbor and siltation in Redwood Creek.

In addition, the restoration design of Inner Bair includes the improvement of certain levees to provide greater protection of existing infrastructure, the construction of new levees and berms to facilitate dredged material placement, and the use of dredged material to create upland and upland transition areas. These features, plus design elements that minimize mosquito breeding, are discussed in greater detail in the following sections.

7.3.1 Breaches

Breach Locations. The number and location of breaches were selected as shown in Figure 2 to achieve a balance between four primary objectives:

(1) to reestablish and rejuvenate the natural preexisting drainage network,
(2) where possible to emphasize the recreation of higher order (larger) tidal channels within the marsh restoration areas,
(3) to avoid breaching Middle and Outer Bair to the east of the channel flow control structures, and
(4) to limit construction costs by limiting the number of breaches and associated cut-off berms.

In support of objectives 1 and 2, we placed breaches at the mouth of each large natural drainage network (breaches OB1, MB1, IB1, and IB2)[2].

Historically lower order[3] channels serving small drainage areas that connected directly to one of the major sloughs surrounding the islands drained much of the site. The reconnection of many small drainages directly to the major sloughs was considered to be cost-prohibitive. For the smaller channels, we included one breach for each collected drainage area of approximately 70 acres or more (OB3, OB4, MB4, MB5). Seventy (70) acres of tidal drainage will allow the formation of at least third order channels and larger. Because of infrastructure constraints (Section 7.4) Middle and Outer Bair could not be breached along the eastern parts of Smith and Corkscrew Sloughs. The southeast part of Middle Bair will drain to breaches to the north and west and this area will tend to experience poorer drainage than the rest of Middle Bair.

Two breaches have been included on Inner Bair Island. The breaches are located at the confluence of the preexisting slough channel and Smith Slough and will reestablish the major historical tidal connections. No additional breaches were included because they would have limited public access to much of the site. Two breaches were incorporated into the design, rather than only one, to create habitat in the area between the two breaches that would be isolated from adjacent upland during high tides. A graded upland transition area between the breaches will also help avoid short-circuiting of flow between the breaches.

A small area of fringe marsh on the outboard side of the levees will be excavated in conjunction with the external breaches; however, this area will be minimal, as the existing fringe marsh forms only a narrow band less than 20 feet wide in most locations.

Breach Cross Sections. Breaches will be sized according to the following design criteria: (1) provide full drainage between the slough and the pond (i.e., minimize muting across the breach), and (2) provide reasonable assurance of achieving uninhibited long-term channel formation. Providing full tidal drainage is important for site evolution since restricted drainage has the

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[2] OB = Outer Bair; MB = Middle Bair; IB = Inner Bair; breach numbers are shown in Figure 1).

[3] Channel order is a method of describing the placement of a stream segment with the drainage network. Hierarchical order begins with the smallest of channel segments and increases in order when two channels of the same order connect. Thus, the smallest, singular channels in the system are considered to be first order. When two first order channels join, the subsequent portion of the channel is considered to be second order. A third order channel forms when two second order channels join, and so on. A low order channel, such as a first order channel, joining a higher order channel does not alter the order of the latter. The highest order found in a drainage system is used to define the order of that system. (PWA, 1995)

potential to limit sediment delivery and tidal scour. Sediment delivery on the flood tide is critical to rebuilding the marshplain up to natural pickleweed marsh elevations. Tidal flows scour and reform the remnant tidal channels, recreating the complex tidal channel system and valuable channel-edge habitat.

The importance of reasonably assuring uninhibited channel formation (Criterion #2) is self-evident. Sizing breaches to expected long-term equilibrium depths will promote consistency with this design criterion by preventing compacted levee material or other potential erosion resistant material from inhibiting long-term channel development.

Our estimates of long-term breach dimensions are based on empirical channel relationships developed for the San Francisco Bay estuary. These relationships, referred to as hydraulic geometry, are explained further below. Preliminary sizing is based on expected long-term equilibrium dimensions. Final breach sizing will occur in subsequent design.

Hydraulic Geometry. Hydraulic geometry relationships developed by PWA for the San Francisco Bay area (Appendix 1) were used to size the proposed levee breaches on Bair Island according to their expected long-term dimensions and used to estimate potential temporary breach enlargement in response to tidal scour. The first set of hydraulic geometry relationships relates marsh plain drainage areas or "tidal watersheds" to long-term (equilibrium) channel dimensions (top width and depth) (Figure 15). These were used for breach design on Bair Island. The second set relate tidal prism (the volume of water exchanged between MHHW and MLLW upstream of a given cross section location) to channel dimensions (Figure 16). The channel geometry relationships are derived from data on existing and historic natural tidal marsh systems. The database consists of tidal channel drainage areas, estimated or measured tidal prisms, and correlating channel top widths and depths.

Drainage Areas. Marsh drainage areas and preliminary channel dimensions for the proposed breaches are shown in Table 4. The tributary area of each breach was estimated by visual identification of historic watershed boundaries from aerial photographs and planimeter measurement of watershed areas. Channel top widths and depths were derived directly from the hydraulic geometry relationships; bottom widths were calculated using a side slope of 4:1 (horizontal: vertical), according to the channel top width and depth[4]. Thalweg[5] elevations are calculated by subtracting the depths from a starting elevation of MHHW. Two of the larger drainage networks reestablished in this design (Middle Bair 1 and Outer Bair 1) will be deep enough to provide sub-tidal habitat for a significant length of channel, with depths of approximately 2 feet at MLLW.

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[4] In some of the smaller breaches this method yields a calculated negative bottom width. This unrealistic bottom width estimate is a function of the side slope used in the calculation. The side slopes of a natural channel are generally steeper than the 4:1 that can be constructed. In these instances, we used a minimum bottom width of 5 feet and back-calculated a wider top width.

[5] The thalweg is the deepest point in the channel.

Table 4. Expected Long-Term Breach Dimensions

Location	Marsh area (acres)	Top width (ft)	Bottom width (ft)	Depth (ft)	Thalweg el. (ft NGVD)	Water depth at MLLW (ft)
Inner Bair 1	96	84	13	8.9	-4.8	0.9
Inner Bair 2	96	84	13	8.9	-4.8	0.9
Middle Bair 1	277	151	64	11.0	-6.9	3.0
Middle Bair 3	161	112	34	9.8	-5.8	1.9
Middle Bair 4	79	76	8	8.5	-4.5	0.6
Middle Bair 5	81	77	8	8.6	-4.5	0.6
Outer Bair 1	210	130	47	10.4	-6.3	2.4
Outer Bair 3	68	71	5*	8.3	-4.2	0.3
Outer Bair 4	77	75	7	8.5	-4.4	0.5

*Assume a minimum bottom width of 5 feet.
Note: Because of the updates to the design, breach numbers are not consecutive. There is no OB2 or MB2.

Expected Transitional Channel Geometry. Since the site may take many decades to evolve to an equilibrium condition, it is important to have a general understanding of the channel forms and overall marsh morphology that may be present during the transition period between initial breaching and eventual equilibrium. In general, since Inner, Middle and Outer Bair Islands will be below natural marshplain elevations at the time they are breached, this will allow a greater tidal prism to pass through the breaches relative to long-term equilibrium conditions. Since the smaller long-term dimensions were used in preliminarily breach sizing, there may be a tendency for the breaches to scour and enlarge. However, as sedimentation inside the sites begin to raise marsh plain elevations, tidal prism and scour will decrease, and channels will experience deposition, until the system eventually reaches equilibrium. Calculations of breach dimensions based on the large initial tidal prism indicate that top widths could increase to 80 - 200 feet and channel depths to –5 to –10 ft NGVD, or 1 to 6 feet deep at MLLW.

7.3.2 Channel Connectors

Channel connectors will be excavated through interior levees on Middle Bair to allow the reestablishment of historical flow paths between internally leveed areas (Figure 2). On Inner Bair, an excavated channel connecting the southeast corner of the island to the main channel will facilitate complete drainage of the site. Like the breaches, the connectors were sized according to expected long-term equilibrium dimensions using marsh area vs. channel dimension hydraulic geometry relationships.

7.3.3 Cut-off Berms

Excavated material from breach creation will be placed on site to block and partially fill borrow ditches in several locations on Inner Bair, Middle Bair, and Outer Bair (Figure 2). These features, referred to in this report as "cut-off berms," are designed to direct flow into the historic tidal channels and to prevent the borrow ditches from becoming the primary drainage network after tidal action is restored to the marsh. The cut-off berm prevents flows from draining through the full length of the borrow ditch, but allows the ditch to convey flows from the many low-order channels on Bair Island (that historically drained directly to the marsh perimeter) to one of the proposed breaches. Because flow is blocked, the perimeter borrow ditches are eventually expected to silt in along some of their length.

In this design, one cut-off berm is located between each pair of breaches. Additional cut-off berms are specified in selected areas. Cut-off berm elevations will be between approximately one foot above the adjacent marshplain elevation (to allow for one foot of settling) and MHHW.

7.3.4 Levee Lowering

Portions of certain levees on Middle and Outer Bair Islands may be lowered to provide a source of fill for construction. The design elevation for levees after lowering will be between approximately 5 and 6 feet NGVD. This will create upland transition habitat and provide wave-breaking function, while still being low enough to serve as a source of fill. The existing levee crests are between approximately 6 and 9 feet NGVD and support primarily non-native upland vegetation such as Italian ryegrass (*Lolium multiflorum*), black mustard, wild radish and ice plant. The total area of levee that is lowered will depend on the amount of fill needed for construction of borrow ditch cut-off berms on Middle and Outer Bair. It is not anticipated to be economical to use this fill for construction of dredged material placement berms and levee improvements on Inner Bair.

Levees will be left in place to (1) promote marshplain evolution and (2) protect levees along the west side of Steinberger Slough from shoreline erosion. The primary wind direction is from the west-northwest, with shorter duration winter storms from the southeast.

7.3.5 Upland and Transitional Habitat Areas

Approximately 22 acres of upland habitat will be created on Inner Bair Island, by filling the area within the San Carlos Airport Safety Zone levees. Although the purpose of the fill is infrastructure protection (Section 7.4), the upland area will provide upland habitat and high tide refugia. Two upland transition areas will be created. One transition zone, approximately 2 acres in area, will surround the eastern side of the San Carlos Airport Safety Zone and the other, approximately 1 acre in area, will extend southward from the levee on the island between the two proposed breaches (Figure 3). Elevations of the transition area will range between 0.25 feet above and below the high spring tide elevation (approximately 5.05 feet NGVD).

7.3.6 Design Elements that Minimize Mosquito Breeding

Bair Island is a known breeding location for the California salt marsh mosquito (*Aedes squamiger*), which will develop extremely dense, pestiferous populations if left untreated (San Mateo County Mosquito Abatement District, 1997). Mosquito control initiatives began in 1990 and include surveillance, siphoning of diked salt ponds, and larvicide and insecticide application from the ground and the air. The restoration of Bair Island should improve conditions by opening five diked salt ponds to tidal action, thus reducing the amount of breeding habitat. The Technical Committee for the Development of Vector Prevention Standards (1986) proposed a series of guidelines for marsh restorations projects. These include providing for free tidal flow through deep channels, adequate levee breaches to ensure proper tidal circulation, and avoiding the creation of areas that will pond water. All of these design elements were taken into careful consideration at Bair Island.

Also of concern with regards to vector control is the beneficial reuse of dredged material at Inner Bair Island. To minimize potential mosquito breeding habitat, adequate drainage must be provided to dewater the dredged material. As the material consolidates, periodic disking and spreading of the dredged material is also recommended. This serves to prevent mosquito breeding in water that subsequently collects in cracks and depressions in the dredged material (Technical Committee for the Development of Vector Prevention Standards, 1986).

7.4 PUBLIC USE INFRASTRUCTURE DESIGN

Public access to Inner Bair Island will be along an out-and-back trail on the levee tops along the San Carlos Airport Property Levee and the Inner Bair Island levee to viewing/environmental education platforms on Smith Slough (Figure 18). The unpaved trail will extend from the Refuge entrance at Whipple Avenue to the north around the San Carlos Airport levee and to an observation platform near the northern breach. The levee trail will also extend to the south towards Pete's Harbor to an observation platform located south of the southern breach. For the benefit of providing wildlife with a area of refuge from human impacts and to allow boating through the realigned Smith Slough, no public access will be permitted between the two breaches on Inner Bair Island. A small craft portage will be constructed around the flow restrictor in Corkscrew Slough to facilitate boating until head and velocity equalize. There will also be a depth gage in the V-cut of the Corkscrew Slough flow restrictor to enable boaters to estimate available draft for passage. Warning signs will be placed on both sides of the flow restrictor on Corkscrew Slough to warn boaters of their location and how to safely navigate. Interpretive signs will be placed at the Redwood City boat ramp about the flow restrictors in Corkscrew Slough and Smith Slough.

The interpretive signs at the Redwood City boat ramp will also contain information on how to pass the harbor seal haulout sites without disturbing them. An orientation kiosk with regulatory and interpretive signs will be located at the entrance to Inner Bair Island. Wildlife observation platforms with interpretive signs will be built at the small craft portage and the flow restrictor at Corkscrew Slough. The Refuge's existing Bair Island parking lot on Bair Island Road will be maintained, and public sanitary facilities will be provided.

7.5 INFRASTRUCTURE PROTECTION

Infrastructure protection will be required for the San Carlos Airport safety area, the SBSA force main, the Redwood Creek shipping channel, Pete's Outer Harbor, and the public path on Inner Bair.

7.5.1 San Carlos Airport Safety Area

The restoration design of Inner Bair Island must provide protection for existing infrastructure after the site is opened to tidal action. In the case of the San Carlos Airport Safety Zone, the restoration plan includes the construction of a levee around the perimeter of the Airport property that is designed to provide the same level of flood protection to the area as under existing conditions, while also serving as a dredged material placement berm. This levee has a design elevation of 6.6 feet NGVD and a typical cross section as shown in Figure 17. The U.S. Fish and Wildlife Service and the project team have been in contact with Airport authorities regarding the treatment of the Safety Zone and the decision to fill this area represents a coordinated effort to meet the Airport's needs while providing habitat that fulfills the Bair Island restoration objectives (Appendix C). This area will be filled with dredge material to an elevation that will facilitate the establishment of an upland plant community.

7.5.2 South Bayside System Authority Sewer Line

The portion of the Inner Bair Island levee along the SBSA force main will be improved in order to provide increased protection against erosion and provide inspection and maintenance access to the sewer line after the island is opened to tidal action. The improvement will likely include the extension of the levee toward the inside of the island and will match the existing elevation of approximately 7.5 feet NGVD. This elevation will provide protection against approximately the 100-year high tide (7.3 ft NGVD). The levee improvement, which is being designed with the SBSA, has not been finalized at this time. The Refuge will work with SBSA to develop specifications in a subsequent design phase.

7.5.3 Channel Flow Control Structures

Flow control structures would be constructed at Smith and Corkscrew Sloughs to mitigate for potential impacts to Redwood Creek shipping channel siltation rates and Pete's Outer Harbor tidal velocities. Corkscrew Slough would be blocked to the east of the Middle Bair breaches (see location in Figure 2). This would not necessarily be a complete block; a small notch would be included to allow some flow across the structure. Two design concepts were considered at each location: a quarry stone berm and a linked cellular coffer installation. The natural channel is approximately 300 feet wide with a thalweg of approximately –10 ft NGVD at the selected location. The design assumes a notch approximately 30 feet wide at the top (crest at 5.1 ft NGVD), down to 2 ft below MLHW (0.6 ft NGVD). The structure would tie into high ground on both sides. Final design of the flow restrictors will integrate flexibility so that the structures may be modified after installation in order to ensure that flood hazards are not significantly affected (Appendix H).

Smith Slough would be realigned to its historic meander with a block between the two Inner Bair breaches. The structure would be similar to the structure at Corkscrew Slough, but would not be notched. The eastern Inner Bair breach (IB2) will be sized to convey the same amount of tidal flow as is currently conveyed in Smith Slough at this location. To meet this criterion, the breach will be undersized relative to post-restoration flows and will need armoring to protect it from tidal currents of up to 10 feet/second.

Impacts to boating would occur after levee breaching but reduce over time as conveyance along Steinberger Slough improves due to tidal scour. Immediately after tidal restoration, high velocities and head differences would limit the hours of each day that boats would be able to pass the flow restrictors. This window for boating will gradually increase as tidal sloughs adjust to the restored tidal prism and reach a new equilibrium.

7.5.4 Public Path on Inner Bair

Some parts of the public path on Inner Bair may need to be raised to reduce the frequency of tidal flooding. Approximately half the existing path length is already subject to direct tidal inundation from the adjacent sloughs. Tidal inundation frequency for these areas is not expected to change. The other half of the path is currently protected from tidal flooding by the perimeter levee. This part of the path could be affected. Exact path elevations are not available, but are generally between 6 and 8 feet NGVD (Bohley Maley Associates, no date). This is above the elevations of spring tides (approximately 5.0 feet NGVD, or one foot above MHHW), but below the 5 and 10-year high tides (6.3 and 6.6 ft NGVD, respectively). An updated survey of the existing access trail loop is recommended in subsequent phases of the design to estimate more accurately its current inundation frequency and potential need for raising the trail in selected areas.

Tidal action on the inside of the island will also create some initial increase in erosion from wind wave action, where the maximum fetch length is approximately 4000 feet in the predominant wind direction (west-northwest). The perimeter levees will require monitoring and maintenance to preserve trail access. The potential for erosion will be highest in the short-term, before the marshplain is fully developed, although filling the site to approximately 2.5 feet NGVD will reduce wave action by limiting the water depth. As the marshplain becomes vegetated, wave energy will be dampened by vegetative roughness. Also, as the marshplain rises through sedimentation, the water depth decreases, decreasing the height of waves that form and propagate over the site.

7.5.5 Flood Management for Pulgas and Cordilleras Creeks

Implementation of the Preferred Alternative will redirect flows from Pulgas and Cordilleras Creeks away from the deep Redwood Creek Shipping Channel in order to meet project constraints. This action is expected to increase peak water levels at the Highway 101 crossings by approximately 0.05 ft (less than an inch) during a 100-year flood event, although these changes are expected to diminish over time as Steinberger Slough deepens over the fist months and years. Details of the flood analysis are presented in Appendix H.

7.6 PUBLIC USE PLAN

Prior to the acquisition of Bair Island by the Refuge, Inner Bair Island was privately owned. For many years, the landowners attempted to limit access and prevent trespassing on Inner Bair Island (Don Warren, pers. comm.). However, after many failed attempts to block all public access (including motorcycles and all-terrain vehicles) to Inner Bair Island, the landowners allowed foot access to the levees and pathways on Inner Bair Island. Since acquiring Bair Island, the Refuge has maintained the same level of public access until a public use plan could be generated for the entire Bair Island complex.

Due to the numerous members of the public who utilize Bair Island to walk their dogs, it was determined that Alternative 3 (Moderate Public Access With Pets) would be the preferred public use alternative. Under this alternative, dogs will be allowed on leash and on trail for a test period of 3 months to determine the impacts to wildlife (please see Appendix D for a complete description of the test period criteria). If owners cannot keep their dogs under control during this trial period and potential impacts to wildlife are considered too great, then dogs will be restricted from Bair Island.

Public access to Inner Bair Island will be along an out-and-back trail on the levee tops along the San Carlos Airport Property Levee and the Inner Bair Island levee to two viewing/environmental education platforms on Smith Slough (Figure 18). For the benefit of wildlife using Inner and Middle Bair Island and to allow boat passage through the realigned Smith Slough, no public access will be permitted along the rest of Smith Slough. An orientation kiosk with regulatory and interpretive signs will be located at the entrance to Inner Bair Island. The Refuge's Bair Island parking lot on Bair Island Road will be maintained, a trail from the parking lot to Inner Bair Island will be established and public sanitary facilities will be provided. The Refuge will work with Caltrans to close the existing dirt parking area along Whipple Avenue once the trail from the Refuge's parking lot to the Inner Bair Island trailhead is upgraded and made safer for public use. Following the implementation of the entire trail system, there will be a net increase in the total length of trails on and adjacent to Inner Bair Island as the trail from the parking lot to the levee trail will be added to the system. The length of trail that will be added to the system is twice as long as the trail section that will be removed.

There will be no Public Access to Outer and Middle Bair Island except by Refuge guided trips and other specific exceptions that are approved by a Refuge Special Use Permit, and to a single viewing platform, accessible only by boat, located on Middle Bair Island. Fishing from boats in Smith and Corkscrew Sloughs will be allowed, however fishing will not be permitted from land. Hunting of waterfowl on Outer and Middle Bair Islands will be permitted as per federal, state and city regulations.

Access (both on trail and by boat) has been limited in this preferred alternative to protect sensitive wildlife species at Bair Island. This is based upon a large volume of research conducted on the effects of various recreational activities on wildlife (Burger 1981, Pfister et al. 1992, Rogers and Smith 1995, Burger 1998, Suryan and Harvey 1999, Schummer and Eddleman 2000, Rodgers and Scwikert 2002). Recreation is becoming more of a concern as human use of wild areas increases, and the size of those areas decreases. Thus, humans and wildlife are more and more likely to come into contact.

Waterbirds, both shorebirds and waterfowl, vary dramatically according to species in how they react to human presence. During the non-breeding season, birds such as mallards and gulls tend to have a relatively high threshold of disturbance. However, during the breeding season most wildlife is very protective of nests and offspring, and their tolerance to disturbance drops. Even during the non-breeding season, disturbance may have an equally detrimental effect on the animals although not as obvious an effect. It has been demonstrated that human activity in wild areas is correlated with declines of breeding populations in birds (Knight and Gutzwiller 1995).

Activities involving rapid movement and loud noise (e.g., power-boating, water skiing) have been found to rank the highest in level of disturbance to waterbirds (Mathews 1982). Some documented impacts of motorboats include shoreline degradation, disruption of nesting and feeding resulting in a loss of production, as well as displacement of birds. Not only can the noise be a disturbance and cause a bird to flush, but the bow waves can flood exposed nests. Motorboats can flush waterbirds and interrupt feeding for a much longer period than can quieter, slower activities (such as canoeing and kayaking). Therefore, to decrease the level of disturbance, all motorized vehicles (i.e., motorboats, personal water crafts, jet boats and hovercrafts) will be subject to "no wake zone, maximum 5 mph for motorized water vehicles" in Smith and Corkscrew Slough. No motorized vehicles will be allowed within areas currently inside the exiting levee.

7.7 DREDGED MATERIAL PLACEMENT

7.7.1 Background Discussion

Dredged material will be placed on the majority of Inner Bair to encourage rapid site development and limit the potential for increased bird strike hazard at the adjacent San Carlos Airport. The two basic methods for delivering dredged material for fill to a beneficial reuse site such as Inner Bair Island are hydraulically and mechanically. Hydraulic dredging/delivery is mixing the sediment with large quantities of water and pumping it into the site through a pipeline as slurry. Typical slurry densities are 10-20% sediment and 80-90% water. The process water is then decanted, after the sediments have settled out, and returned to the Bay.

Mechanical dredging/delivery would typically involve excavating the material with a clamshell or excavator dredge and placing the material in a barge, transporting the barge to Inner Bair Island and using a clamshell dredge to take the material out of the barge and place it onto the Island. Alternatively, the barge could be hydraulically off-loaded onto Bair Island. However, both of these methods are significantly more equipment and labor intensive and therefore, substantially more expensive than, hydraulic dredging with direct material placement in the fill areas.

If the dredging area was located nearby, such as the Redwood City Harbor, a hydraulic dredge could dredge the material and pump it directly into the site. If the dredging area were distant (virtually any project except Redwood City Harbor) the material would need to be transported to the site in a barge and off-loaded.

Due to the large surface area, fill depths and grades necessary to create the desired tidal wetland habitat and additional material needed for transitional and upland habitat creation areas, the hydraulic placement of fill is likely the more feasible and cost effective construction alternative for the majority of fill required for the project. This assumes the use of fine-grained dredged materials, such as the material from Redwood City Harbor. However, there may be opportunities to receive mechanically placed material early in the project and use that material for levee and berm construction, or later in the project and use the material for the upper layers or transitional habitat areas.

7.7.2 Areas Requiring Filling

The three basic areas that require filling are: the Airport Safety Zone; the tidal wetland restoration area inside the remnant slough channel; and the tidal wetland restoration area outside/surrounding the remnant slough channel (Figure 3).

Three significant design objectives guided the development of this plan for placement of dredged material: (1) keeping fill out of the existing major remnant sloughs; (2) minimizing the potential for dredged material to migrate out into Smith Slough after breaching the exterior levees of Inner Bair Island; and (3) dividing the site into dredged material placement cells to accommodate the receipt of dredged material from two separate mobilization events (the expected need for two mobilizations is discussed later). In addition it is recognized that the sediment quality of available dredged materials must be suitable for wetland use.

To meet the design objectives, internal berms on Inner Bair Island are proposed to control the lateral extent of dredged material placement (Figure 3). These internal berms would be constructed prior to any placement of dredged material with conventional land based heavy equipment such as scrapers, dozers, graders and trucks. This report assumes that these berms would primarily be constructed from native soil material borrowed from within the areas of Inner Bair to be filled. The SBSA levee improvements will also be constructed with on-site material prior to dredged material placement.

The borrow areas for the levee and berm materials should not be directly adjacent to the levees/berms. The borrow areas should be shallow excavations (1 to 2 foot maximum) spread over relatively large areas. This is desirable to preclude having large differences in the fill depths within the upland and tidal habitat areas that will result in relatively large differential settlement over time.

7.7.3 Conceptual Hydraulic Filling and Process Water Management Plan

Dredged material placement will occur within the interior levees and berms (discussed above) to contain the hydraulically placed fills. Decanting weirs placed in these levees and berms would be used to control material placement elevations, de-watering operations and discharge water quality.

In the San Carlos Airport Safety Zone, care should be taken during implementation in order to avoid creating conditions that might attract birds. If the dredge material utilized contains significant numbers of invertebrates (such as polychaete worms, clams or snails), we would expect gulls to be attracted. This would likely last only a few days after each supra-tidal application of dredge spoil that contained invertebrates. The density of foraging gulls would be roughly proportional to the density of invertebrates. This has been observed during the dredging operations at Oakland City Harbor. We would not expect further foraging after any invertebrates had died or been eaten (a few days to a week maximum), as invertebrates are not likely to colonize supra-tidal dewatering mud.

We would expect shorebirds to be attracted to any ponding water in depressions formed in the dredge spoils. Care should be taken to apply the dredge in such a way as to minimize the formation of depressions. Any depressions that do form should be filled with dredge material as soon as possible. Other birds should not be attracted to the dewatering dredge spoil as either loafing or foraging habitat. Once dewatered, non-native grasses and other invasive forbs would likely colonize the site. We would recommend seeding the area with native grasses, forbs, shrubs and possibly peripheral halophytes such as alkali heath (*Frankenia salina*), salt grass (*Distichlis spicata*), and marsh gumplant (*Grindelia stricta*).

Tidal Wetland Areas. The required design elevation (approximately +2.5 feet NGVD) for Inner Bair Island tidal wetland habitats will initially require the placement of 2 to 3 feet of fill. This depth of fill could likely be placed in one filling sequence. Typically the fill would be maintained in a saturated condition for six months to one year to allow for consolidation. After this period, the fill is typically stable enough that the introduction of tidal action will not cause massive erosion or fill movement problems. The current regional practice for tidal wetland fills is to keep them saturated to prevent potential undesirable chemical and pH changes and to prevent problems from wind blown dust/material movement.

For the tidal wetland areas on Inner Bair, the decanting weirs would be placed in the berms protecting the remnant slough channel. A discharge weir would be located in the northern levee (along Smith Slough) at the future breach location. The remnant slough area, protected by the berms, would provide a storage and settling area for process water. The process water would be discharged from the remnant slough into Smith Slough though the discharge weir located in the northern levee. The discharge weir would be high enough to prevent high tides from entering Inner Bair while still being low enough to allow process water to flow out of Inner Bair.

Upland Area. To meet the required design elevation (approximately +6.6 feet NGVD) for the San Carlos Airport Safety Zone upland habitat area, 7 to 8 feet of fill will be placed. Sequential filling with two or more lifts will likely be required to achieve a stable fill configuration in this area. The initial lift(s) of material will attain a more stable configuration if they are allowed to thoroughly dry and desiccate prior to additional material placement. Further geotechnical and design analysis of specific site and fill material characteristics will be required to produce a specific fill plan for this area.

7.7.4 Dredged Material Volumes

At this stage of design analysis, only preliminary, gross fill volumes for the proposed restoration areas are available. To refine these fill estimate volumes further, additional geotechnical investigation and design analysis are required. Based on the preliminary calculated gross fill volumes, approximate dredged material volume requirements were developed for the tidal and upland fill areas. These approximate dredged material volumes are presented in Table 5 below and assume that:

- The tidal wetland areas could be filled in a single lift and the material always remains saturated;
- The upland area fills will be placed in multiple lifts and thoroughly dried between lifts; and
- Fine-grained sediments such as young bay mud from Redwood City Harbor are used.

Table 5. Approximate Fine Grained Dredged Material Volume Requirements

Area	Approximate Dredged Material Required In Situ (cubic yards)
Tidal Area A - Inside Remnant Slough	200,000
Tidal Area B - Outside Remnant Slough	600,000
Airport Safety Zone - Upland	250,000
TOTAL	**1,050,000**

7.7.5 Dredged Material Sources and Timing

Redwood City Harbor is the closest frequently dredged area to Inner Bair Island. All other currently known potential sources of dredged materials are significantly further away. Therefore, the Redwood City Harbor is likely the only source of dredged material that is close enough to be directly hydraulically placed on the site (economically).

Redwood City Harbor typically has a Corps of Engineers maintenance-dredging event every three years. The last maintenance-dredging event was in 1999. The next scheduled event is in FY 2005 (October 2004 – September 2005). Volumes from dredging events within the last 20 years have ranged from 250,000 to 970,000 cubic yards. The average dredging volume is approximately 600,000 cubic yards. The planning volume for future maintenance dredging events currently used by the LTMS is 430,000 cubic yards. In addition, the Port of Redwood City plans to dredge the berths themselves, and expects to dredge 35,000- 40,000 cubic yards in 2004.

Given the current estimate of dredged material volumes required for Inner Bair, it would likely take at least the next two maintenance dredging events at Redwood City Harbor to fully construct this project. Depending on the actual volume dredged during these events additional material supplies may also be required.

Bair Island is not the only wetland project interested in receiving dredged materials from the Redwood City Harbor. The Hamilton Wetlands Restoration project (Novato, CA) and the Montezuma Wetlands project (Solano County, CA) are also planning to receive future dredged materials from Federal maintenance dredging projects, including the Redwood City Harbor project.

Other potential dredging projects that could provide dredged materials to this project include:

- Port of Oakland – 50 ft Deepening project (2001 to 2005)
- San Leandro Marina Maintenance
- Port of Oakland Maintenance Dredging (annual)
- Port of San Francisco Maintenance Dredging (annual)
- Foster City Lagoons
- Other Federal and private dredging projects north of the Bay Bridge.

The economic, social, and political acceptability of these potential sources, as well as the dredged material physical and chemical suitability for this project, will need to be determined if they are considered.

7.7.6 Dredged Sediment Quality

Any dredged materials used as fill for tidal wetlands restoration are typically required to meet the wetland cover material criteria and guidelines in effect at the time of project approval. Revision of these guidelines has been underway in the San Francisco Bay region for some time and proposed new guidelines are currently under an extended review by state and federal regulatory agencies and the public. Therefore, the specific chemical and physical criteria or guidelines for dredged materials are not currently known.

The dredged materials from the federal maintenance dredging of the Redwood City Harbor have historically met all testing standards for in-bay disposal. These standards are similar, though not identical, to the standards for wetland cover. Corps of Engineers staff familiar with the maintenance dredging of the Redwood City Harbor have indicated that, based on historic testing, they would expect future maintenance dredging sediments to be suitable for wetland cover material uses (Snitz, pers. comm.)

Dredged materials from other locations would need to be evaluated on a case-by-case and site-by-site basis to determine their potential suitability for use at Inner Bair. This analysis would be based on historic and/or current sediment testing and analysis.

7.7.7 Dredged Material Placement Costs

The actual costs to the Bair Island project for large volumes of dredged material fill on Inner Bair Island could be highly variable and dependent on many source specific factors. The major source specific factors include:

- The dredged material location and timing of dredging relative to the Bair Island project;
- The equipment and labor required to place the dredged material on Inner Bair Island as opposed to the cost of other available placement locations for that material;
- Cost sharing options and/or funding sources available for the beneficial reuse of dredged material from the specific source project;
- The cost of planning, permitting and environmental compliance associated with the source project material being placed on Inner Bair Island;
- Site preparation costs associated with dredged material placement on inner Bair Island;
- The costs (economic and non-economic) associated with the political and social implications of using dredged material from the source project.

Given the level of uncertainty regarding the source(s) of dredged material and site specific design at the current level of project development, it is not possible or appropriate to develop a specific cost estimate or per cubic yard cost (with any reasonable level of certainty) for the dredged material placement on Inner Bair Island. However, the estimated dredged material placement costs from regional studies and other wetland restoration projects can be used as approximate indicators of the typical costs for similar projects in this region. Additionally, several potential sources of dredged material can be discussed relative to the potential funding and cost sharing opportunities for the beneficial reuse of their dredged materials on Inner Bair Island.

Redwood City Harbor Maintenance Dredging. As discussed above, this Federal maintenance-dredging project is located the closest to Inner Bair and is likely the preferable source of dredged material for beneficial reuse on Inner Bair Island. Currently, this U.S. Army Corps of Engineers (Corps) maintenance dredging projects with in-Bay dredged material disposal at Alcatraz site is 100% federally funded by the Harbor Maintenance Trust Fund. It is unlikely that any increased cost (above the cost to dispose at Alcatraz) would be federally funded through the existing maintenance dredging authorization.

Under Section 204 of the Water Resources Development Act of 1996 (WRDA-96) projects for the beneficial reuse of dredged materials for habitat restoration can be authorized and funded on a cost shared basis. The cost-sharing ratio is typically 65% federal and 35% non-federal. For the Redwood City Harbor project the non-federal sponsor is the Port of Redwood City. The Bair Island project could work with the Port of Redwood City to fund a Corps Section 204 project. The Corps, throughout the Long Term Management Strategy (LTMS) project and the Dredged Material Management Office, are very interested in beneficial reuse projects for dredged material that reduce in-Bay disposal.

Once the Inner Bair Island design is refined, detailed cost estimates could be developed to compare the cost of the existing maintenance dredging and in-Bay disposal with dredging and direct placement on Inner Bair Island. If placement on Inner Bair Island could be shown to be less costly, the project could possible be federally funded as a value engineering initiative. This could reduce or eliminate the cost for dredged material placement to the Bair Island project.

Port of Oakland –50 Foot Deepening Project and Maintenance Dredging. Due to the schedule for the Port of Oakland –50 Foot Deepening project and the completed environmental documentation and existing dredge material reuse plans, it is unlikely that any significant dredge material would be available for the Inner Bair Island project (Cardoza, pers. comm.). However, ongoing berth dredging (non-federal) and channel maintenance dredging (federal) may be available within required time frame.

Regional Dredged Material Placement Costs for Restoration Projects. Several recent studies in the San Francisco Bay region, including the LTMS, have looked at the cost of beneficial reuse projects (primarily wetland restoration) relative to the cost of existing in-Bay or ocean disposal of dredged materials. Typically the beneficial reuse project is expected to fund the "incremental cost" of dredged material placement, which is the cost increase due to beneficial reuse instead of traditional in-Bay or ocean disposal. The LTMS studies (LTMS, April 1996) found a range approximately $-0.70 to $+8.50 per cubic yard for the incremental cost for dredged materials going to wetland restoration instead of in-Bay or ocean disposal. Other studies for specific projects in the San Francisco Bay region have found incremental cost within the LTMS range, although primarily positive incremental costs.

Proposed Incremental Dredged Material Cost for This Report. Given the location and timing of nearby dredging and wetland restoration projects in the region as well as regional regulatory trends and other factors, it is likely that the cost (incremental cost) to this project could range upwards of $3.00 to $6.00 per cubic yard for dredged material placement. The distinct potential exists for the Bair Island project to receive dredged material at no cost and/or to receive financial assistance with project design and site construction. However, to be conservative at this level of design it is suggested that an incremental cost of $5.00 per cubic yard be used until further design developments and dredged material supply investigations can be completed. Additionally, it is suggested that a mobilization and demobilization cost of $110,000 per dredged material placement event be used.

7.8 PHASING / BREACH TIMING

Outer Bair will be restored first, followed by Inner and Middle Bair. Full restoration of Outer Bair is preferred and can be implemented as soon as the internal pond features and the flow restrictor along Corkscrew Slough are constructed. If desired to expedite restoration, permitting and construction, Outer Bair could be partially restored prior to construction of the flow restrictor by breaching to Steinberger Slough only (OB1 and OB4, see Figure 2). However, this would require eliminating at least one ditch block to ensure that Outer Bair drains adequately at low tide. Outer Bair could be breached to Steinberger Slough (at OB3) later in construction, once the flow restrictor along Corkscrew Slough has been installed.

Breaching of Inner and Middle must wait until after both channel flow control structures are in place. If Inner and Middle Bair were to be breached before the control structures were constructed, the result would be high velocities at Pete’s Harbor and some additional silting of the shipping channel, though this second effect will be limited in extent and duration. To avoid flooding problems, the Smith Slough control structure will be installed after dredged material placement on Inner Bair is complete. It may be possible to refine the design later to provide for earlier phased breaching of parts of Middle Bair to Corkscrew Slough. Channel flow control structures will be constructed during the dry season, to reduce the potential for flood risks before Inner and Middle Bair are breached.

7.9 ANTICIPATED CONSTRUCTION METHODS

This section provides anticipated construction methods and structure detail that was used as the basis for the preliminary volume and cost estimates in Section 7.9. Preliminary dimensions for the design features are shown in Table 6. These construction methods are preliminary and will be refined during further design development. For cut and fill balance, bulking is assumed to approximately offset losses.

Table 6. Preliminary Dimensions by Design Element

Fill Activities	Design Elevation After Settlement (ft NGVD)	Design Width (ft)	Side Slope (horizontal: vertical)
SBSA levee improvement	+7.5 crest	20 top	4:1 inboard
Safety Zone levee	+8.6 crest	16 top	5:1
Dredged material placement berms	+4.5 crest	12 top	4:1
Transition habitat areas	+4.1 to +5.8 top	NA	15:1
Cut-off berms	+2 to +4	12 top	5:1
Dredged material for tidal wetland	+2.5 top	--	--
Dredged material for upland	+6.6 top	--	--
Excavation Activities			
Breaches	Per Table 2	Per Table 2	4:1
Starter channels	3 deep from surface	10 bottom	2:1
Channel connectors	Per hydraulic geometry calculations	Per hydraulic geometry calculations	4:1
Levee lowering	+6 top	--	--

7.9.1 Inner Bair

Work items to be completed on Inner Bair Island include the following (Figure 3):

- Excavation of levee breaches and an interior "starter" channel,
- Structural fill, including installation of cut-off berms, improvements to the existing perimeter levee (adjacent to SBSA force main), a new levee, and dredged material containment berms, and
- Dredged material placement.

Given the combination of adequate land access and limited number of breaches, it is assumed that the Inner Bair excavation and fill activities will be completed with land-based equipment suitable for use in the marsh environment. A combination of land-based and floating equipment will be required to complete the dredged material placement. Site preparation activity may include clearing of debris, improvement of land access and pumping of the site to obtain favorable working conditions.

The basic sequence of construction (following mobilization and site preparation) will likely proceed as follows:

1. Structural fill (levees, dredged material placement berms, transition habitat areas and cut-off berms),

2. Placement of dredged material (which will be phased over multiple work seasons), and
3. Breach of perimeter levees and excavation of starter channels.

Levees. Proposed levee work includes installation of a ring levee around the San Carlos Airport Safety Zone and improvements to the existing perimeter levee that contains the SBSA force sewer main. A combination of local borrow activity and import of fill from off-site will be required to provide fill for levee work. While surplus fill material could be generated by borrow from Middle and Outer Bair, the lack of land access between Inner and Middle/Outer Bair likely precludes cost effective transport.

The levee foundations will be prepared by removal of vegetation and placement of a geo-fabric over the levee footprint. Fill will be installed in lifts. Fill compaction will be attained by routing equipment over each lift (method compaction).

For this estimate, the following assumptions have been made:

- <u>SBSA levee improvement</u> – In the absence of detailed design criteria for the improved levee cross-section at this stage in the design, we presume an additional 20-foot top width installed against the existing perimeter levee. This is approximately double the existing levee top width. The crest elevation will match existing crest elevation after an estimated 3.5 feet of settlement.
- <u>Airport Safety Zone Levee</u> –crest elevation is the upland design elevation plus 2 feet. Offsite import of fill material. Assumes 3.5 feet of settlement.

Import of fill material has been assumed given unknowns such as suitability of marshplain soils as structural fill, and SBSA's preferred improved levee configuration. Additionally, excessive borrow of on-site marshplain material for use as fill will increase the quantity of dredged material required to attain design elevations.

Dredged Material Placement Berms. Dredged material placement berms will be installed to prevent migration of dredged material into the large remnant channel in the center of Inner Bair. These berms will be constructed adjacent to but offset from either side of the channel (Figure 17). Fill for the dredged material placement berms will be generated by local borrow. Construction of the berms will be similar in nature to levees described above. Crest elevation at the tidal wetland fill design elevation plus 2 feet.

Transition Habitat Areas. Transition habitat areas will be installed with fill in two locations: adjacent to the airport safety zone levee and adjacent to the existing perimeter levee between the breach locations. These berms will be extensions of the respective levee cross sections. Fill for transition habitat areas will be generated by local borrow. Construction of the berms will be similar in nature to levees described above.

Cut-off Berms. Construction of the berms will be similar to levees described above. The crest elevation will range between marshplain and mean higher high water elevations. An elevation of +4 feet NGVD was used to calculate initial estimates of cut-off berm fill volume. These "neat line" estimates were then doubled to account for potentially significant construction period consolidation (approximately 1.5 feet of settlement) and other issues. Fill material will be generated by local borrow.

Dredged Material Placement. Dredged material will be placed in the airport safety zone and tidal wetland areas of Inner Bair Island. Dredged material will be placed within containment berms and levees to limit material migration and allow decanting to occur. Dredged material will likely be placed at Inner Bair over the course of two distinct dredging cycles. See Section 7.6 for additional information. We assume that two mobilization and demobilizations will be required.

Breaches. Breaches will be excavated at the locations shown in Figure 3. Initially, inboard and outboard daylight channels will be excavated and the levee crest will be lowered to a practical level of approximately +6 feet NGVD (to include freeboard to prevent high tides from entering the site). Some of the excavated material may be used as fill material for other improvements, depending on construction phasing and suitability of the material for such use. The balance of the material from the initial excavation will be disposed on-site. This operation will involve transport of the material and spreading.

When timing (considering tides, status of other site activities) is appropriate for final breach at each location, the remaining material will be excavated. A portion of excavated material from the final breach may be disposed by sidecasting, however, some on-site disposal, requiring multiple handling steps, may also be required.

Given the limited number of breaches (2) for Inner Bair and available land access, breaching activity will be handled as a dry operation with land-based equipment. Outboard daylight channel length is limited by assumed construction methods (long-reach excavator sitting on marsh pads, etc) to approximately 50 feet outboard of existing levees. Longer channels could be excavated with higher cost, but are not expected to be required at this time.

Interior Starter Channels. An interior "starter" channel will be excavated, located as shown in Figure 3. Starter channel excavation will occur prior to placement of dredged material. Excavation spoil will be disposed locally by spreading.

7.9.2 Middle and Outer Bair

Work items to be completed on Middle and Outer Bair Island include the following:

- Excavation of levee breaches and channel connectors,
- Structural fill for installation of cut-off berms, and
- Levee lowering.

Given the combination of remote (water only) access and multiple breach locations, it is assumed that the Middle and Outer Bair excavation and fill activities will be completed with a combination of floating, amphibious and land-based equipment. Water only access will likely require construction of temporary landings at Middle and Outer Bair for transfer of barge-

transported equipment. Temporary landing construction may include such items as installation of sheet and fender piles, and grading. Site preparation activity may include clearing of debris and pumping of the site to obtain favorable working conditions.
The basic sequence of construction (following mobilization and site preparation) will likely proceed as follows:

1. Earthwork required to install structural fills, including lowering levees as required to generate fill material,
2. Excavation of channel connectors, and inboard and outboard daylight channels at breach locations, and
3. Final breach of perimeter levees.

Cut-off Berms. Dimensions and assumptions are as per Inner Bair. Fill will be generated by perimeter levee lowering and breach excavation. The foundations will be prepared by removal of vegetation and placement of a geo-fabric over the berm footprint. Fill will be installed in lifts. Fill compaction will be attained by routing equipment over each lift (method compaction).

Breaches. Breach excavation on Outer and Middle Bair will be accomplished in a sequence and manner generally consistent with the breaches on Inner Bair, described above. Given the multiple breach locations for Middle and Outer Bair, maintaining a dry operation during breaching activity will not be possible. It is likely that the final breach excavations will be accomplished by floating equipment.

Channel Connectors. Channel connectors are excavations through interior levees to facilitate tidal circulation on Middle and Outer Bair. Assumptions are similar to those for breaches discussed above. Channel connector excavation will occur prior to commencement of perimeter levee breaching activity.

Levee Lowering. Levee lowering will be conducted as required to generate fill for cut-off berm installation on each respective island. Some lengths of the levees along the east side of Steinberger Slough will be retained to provide shoreline erosion protection for the flood control levee along the west side of the slough. Restoring tidal inundation to Middle and Outer Bair introduces the potential for wind waves generated onsite to propagate off-site and cause shoreline erosion. Although the potential for worsening shoreline erosion is considered to be small even if the levees along the east side of Steinberger Slough were lowered to marsh elevations, retaining parts of these levees will provide additional shoreline protection.

Generally, levee lowering will be limited to approximately +6 feet NGVD. This limited lowering will provide a freeboard above high tides in order to maintain dry conditions for construction prior to levee breaching. Obtaining fill material solely by levee lowering represents an extreme scenario. Fill material may also be generated in undetermined quantities by salvage of breach excavation spoils.

In order to generate fill required for the Outer Bair cutoff berms, approximately 12,000 LF will need to be lowered to +6 feet NGVD or approximately 6,000 LF lowered to +5 feet NGVD. These lengths represent 60% and 30% respectively of the approximately 20,000 LF total Outer

Bair levee length. To generate fill required for the Middle Bair cutoff berms, approximately 24,000 LF will need to be lowered to +6 feet NGVD or approximately 12,000 LF lowered to +5 feet NGVD. These lengths represent 71% and 35% respectively of the approximately 34,000 LF total Middle Bair levee length. Fill material can be generated by lowering the existing levees to +6 feet NGVD at a rate of approximately 0.5 cubic yards per lineal foot (CY/LF), or to +5 feet NGVD at a rate of approximately 1 CY/LF.

7.9.3 Channel Flow Control Structures

Smith Slough and Corkscrew Slough Flow Control Structures. The preliminary design concepts for these two structures are similar, except that a small notch is included in the Corkscrew Slough structure to allow some flow to and from Redwood Creek, matching existing flow conditions. Two design concepts were considered at each of these locations: a quarry stone berm installation and a linked cellular coffer installation. The notch included at the Corkscrew Slough location will allow flows at tide levels above elevation +0.6 ft NGVD (2 feet below mean lower high water), with top width of 30 feet. The remaining crest length for the Corkscrew slough structure and the entire crest length of the Smith Slough structure are set at elevation +5.1 ft NGVD.

Design concepts were limited to the structures described above because of the anticipated high head differences across the structure (up to 4 feet and higher) and long lengths across the width of the channel (approximately 300 feet). Other structures may be considered during design refinement. Design inputs and evaluation criteria to be considered include soil conditions and structure settlement, hydrostatic loads, seismic issues, design life, factor of safety against failure and connection with adjacent lands. Design refinement may result in adjustments to estimated structure costs approaching 30 %.

The flow restrictors will be designed so they can be modified, if needed, installation as part of the adaptive management program. The quarry stone berm could be modified by adding or removing stone. Modifications to the linked cellular coffer installation would be more difficult, but may potentially include cutting sections from the steel sheetpile wall or driving it deeper. Options to increase the flexibility of these concepts will be incorporated in subsequent stages of final design.

Inner Bair Breach Armoring. Velocities of up to 10 feet per second are anticipated in breach IB2. A quarry stone armor blanket was developed to guard against erosion at this location. The armor blanket is configured with finish grades matching the design configuration for the breach. The armor blanket assumes a four-foot layer of graded stone with median weight of 1000 pounds placed over a geosynthetic filter fabric that will reduce deformation of the armor due to differential settling and piping of underlying soils.

Potential Impacts from Flow Control Structures. Placement of a barrier in Corkscrew Slough may affect harbor seal access to haul-out sites in the slough (Figure 4). The proposed barrier would be between two currently used haul-out locations, potentially impeding access to at least one of the sites. However, haul-out sites themselves will not be affected. In addition, boat access may be compromised during low tides, or when water exchange through the structure is at its peak.

7.10 PRELIMINARY VOLUME AND COST ESTIMATE

The preliminary quantity and cost estimates for the proposed work items are summarized in Table 7. *These estimates are preliminary and subject to revision.* The preliminary cost estimate is intended to provide an approximation of total project costs appropriate for the conceptual design stage. Costs for individual restoration components have been used to support cost/benefit decisions reflected in the conceptual design. Reductions in the estimated quantities and costs are possible through design optimization. The preliminary excavation and fill volumes and cost estimates will be refined in subsequent phases of design development based on refinement of design objectives, additional topographic and geotechnical data and analysis, and further design development.

The preliminary cost – including final design, permitting, construction, ongoing monitoring and maintenance – is approximately $21M, or $13,700/acre averaged for the entire site. Restoration costs are significantly higher for Inner Bair Island ($49,500/acre) than for Middle Bair ($6,000/acre) and Outer Bair ($2,000/acre). These include the costs of dredged material placement. If the Bair Island restoration project receives dredged material at no cost, the total project cost could be reduced to $13M (an $8M reduction).

The volumes are estimated in place. Cost estimates are based on bid results from similar projects, consultation with construction contractors and engineering judgment. A contingency of 20% has been added to the estimate of total project cost to cover circumstances and design issues not readily apparent at the current stage of project development. The contingency also provides safety against construction cost fluctuations possible in the local heavy construction market.

We assume offsite import of fill material for the SBSA levee improvements and safety zone levee. The cost assumes $16/CY for purchase of fill material and delivery to site, which includes $5/CY for purchase of material and cost of transport for 2-hour roundtrip delivery cycle. The cost of levee installation/improvement could be reduced if import material is available for less than $16/CY delivered to the site and/or if increased use of on-site material is practical. Also, cross sections can be optimized with additional information and design development. Supply of fill for levee work is an issue that will require further investigation.

Project performance monitoring costs assume monitoring at 0, 1, 3, 5, and 10 years after construction. Long-term maintenance costs for public access facilities, new levees, and the three structures described above were estimated by assuming that maintenance would be required approximately 10, 20 and 40 years after project completion. For each of these events, repairs costing 7.5% of the original construction costs were assumed. As an exception, additional long-term maintenance costs were added to the public access facilities to account for possible trails maintenance even though no improvements to the existing trail surfaces are currently planned.

Table 7. Preliminary Volume and Cost Estimate (in 2003 dollars)

ITEM	DESCRIPTION	QUANTITY	UNITS	UNIT PRICE	TOTAL
1	Mobilization, Site Preparation, & Demobilization				
	A. Outer Bair	1	LS	160,000	$160,000
	B. Middle Bair	1	LS	160,000	$160,000
	C. Inner Bair	1	LS	160,000	$160,000
2	Cut-off Berms				
	A. Outer Bair (4 total)	4,800	CY	43	$206,000
	B. Middle Bair (5 total)	7,500	CY	43	$323,000
	C. Inner Bair (4 total)	8,000	CY	22	$176,000
3	Breaches				
	A. Outer Bair (3 total)	6,000	CY	43	$258,000
	B. Middle Bair (4 total)	8,000	CY	43	$344,000
	C. Inner Bair (2 total)	4,000	CY	22	$88,000
	D. Armor Breach IB2	1,500	CY	150	$225,000
4	Channel Connectors				
	A. Middle Bair (4 total)	4,000	CY	43	$172,000
5	Channel Flow Control Structures				
	A. Corkscrew Slough Structure	1	LS	1,500,000	$1,500,000
	B. Boat Portage at Corkscrew Slough Structure	1	LS	100,000	100,000
	C. Smith Slough Structure	1	LS	1,500,000	$1,500,000
6	Misc. Earthwork at Inner Bair				
	1. Improve Sewer Levee	35,000	CY	27	$945,000
	2. Airport Safety Zone Levee	40,000	CY	27	$1,080,000
	3. Interior Channel Excavation	6,000	CY	9	$54,000
	4. Transition Habitat Between Breaches	30,000	CY	11	$330,000
	5. Transition Habitat at Airport Safety Zone	12,000	CY	11	$132,000
7	Dredge Material Placement at Inner Bair*				
	1. Dredge Material Testing for Two Dredge Episodes	2	EA	40,000	$60,000
	2. Mobilization & Demobilization for Dredge Material Placement	2	EA	110,000	$220,000
	2. Airport Safety Zone	250,000	CY	5	$1,250,000
	3. Tidal Wetland Area	800,000	CY	5	$4,000,000
	4. Tidal Wetland Dredge Material Placement Berms	60,000	CY	11	$660,000
8	Planting at Inner Bair	10	acres	8,000	$80,000
9	Public Access Facilities				
	1. Observation Platforms at Inner Bair	2	EA	75,000	$150,000

ITEM	DESCRIPTION		QUANTITY	UNITS	UNIT PRICE	TOTAL
	2.	Observation Platform at Corkscrew Slough	1	EA	95,000	$95,000
	3.	Chemical Toilets	2	EA	10,000	$20,000
	4.	Cement Pad and Fence around Toilets	1	EA	20,000	$20,000
	5.	Interpretive and Orientation Signs	17	EA	7,500	$127,500
	6.	Regulatory Signs	8	EA	5,000	$25,000
	7.	Warning Signs for Flow Restirctors	4	EA	6,000	$24,000
	8.	Directional Signs for Inner Bair Trail and Corkscrew Portage	4	EA	75	$300
	9.	'Area Closed' Signs	20	EA	20	$400
	10.	Interpretive/Orientation Kiosk	1	EA	10,000	$10,000
10	Permitting and Final Design					
	1.	Permitting	1	EA	20,000	$20,000
	2.	Final Design	1	EA	1,000,000	$1,000,000
11	Monitoring		10	years	60,000	$600,000
12	50-year Maintenance Costs					
	1.	Airport Safety Zone Levee	50	years	4,800	$240,000
	2.	Sewer Levee	50	years	4,300	$215,000
	3.	Breach IB2 Armor	50	years	1,000	$50,000
	4.	Corkscrew Slough Structure	50	years	6,000	$300,000
	5.	Smith Slough Structure	50	years	6,000	$300,000
	6.	Public Access & Trails	50	years	900	$45,000
	7.	*Spartina alterniflora* eradication	5	years	50,000	$250,000
	8.	Predator management	10	years	2500	25,000
Sub-Total			---	---	---	$17,700,200
Contingency (20 % of Project Total)			---	---	---	$3,540,040
Estimated Total Cost			---	---	---	$21,240,240

For detailed explanation of dredged material placement costs, see Section 7.6.

8.0 SITE MAINTENANCE, MONITORING AND ADAPTIVE MANAGEMENT

The restoration of Bair Island has been designed to minimize the necessity of long-term intervention by management personnel. However, some site maintenance will be required for infrastructure protection and to ensure successful restoration of Bair Island to tidal salt marsh habitat that is dominated by native vegetation. Additionally, monitoring of – and possible changes to – the flow control structures will be carried out to ensure that flood hazards do not exceed their expected levels after project implementation.

To protect infrastructure, regular inspections and maintenance will be conducted for the airport safety zone levee, SBSA sewer line levee, flow control structures, and public access facilities. Although no project impacts are expected, the Steinberger Slough levees adjacent to Redwood Shores will also be monitored and maintained as needed.

The successful eradication of smooth cordgrass for Bair Island will require ongoing maintenance as outlined in Section 7.2.1. Other non-native species such as perennial peppergrass (*Lepidium latifolium*), yellow star-thistle (*Centaurea solstitalis*), and ice plant (*Carpobrotus edulis*) are also prevalent on portions of Bair Island. However, the majority of these plant species are naturalized in California, and only perennial peppergrass poses a threat to the marsh plain itself. Eradication programs for species besides smooth cordgrass should be evaluated as an adaptive management strategy if site evolution monitoring illustrates a problem with a particular species. At that time, colonization rates can be determined and the appropriate eradication method for that species applied. However, at this time only smooth cordgrass is anticipated to be a significant threat to the habitat integrity.

The Proposed Action is expected to increase peak flood water levels at the Highway 101 crossings of Pulgas and Cordilleras Creeks during a 100-year flood event by approximately 0.05 ft due to construction of the flow control structures in Smith and Corkscrew Sloughs (PWA 2003). These increases are expected to decrease over the first months and years following project implementation as tidal scour increases conveyance along Steinberger Slough. To manage the uncertainties associated with the hydraulic characteristics of the flow control structures and morphological adjustments along the slough, the Proposed Action includes monitoring of water surface elevations and flow velocities to evaluate whether the structures are functioning per the design criteria given in the Restoration and Management Plan and incorporated into the model used to estimate impacts to flood hazards. The USFWS will be responsible for adjustments to the structures after construction that may be needed to meet the design criteria. The structures will be designed to allow adjustments (such as the addition or removal of rip-rap, or adjustment of weir elevations) for flexibility of post-construction management.

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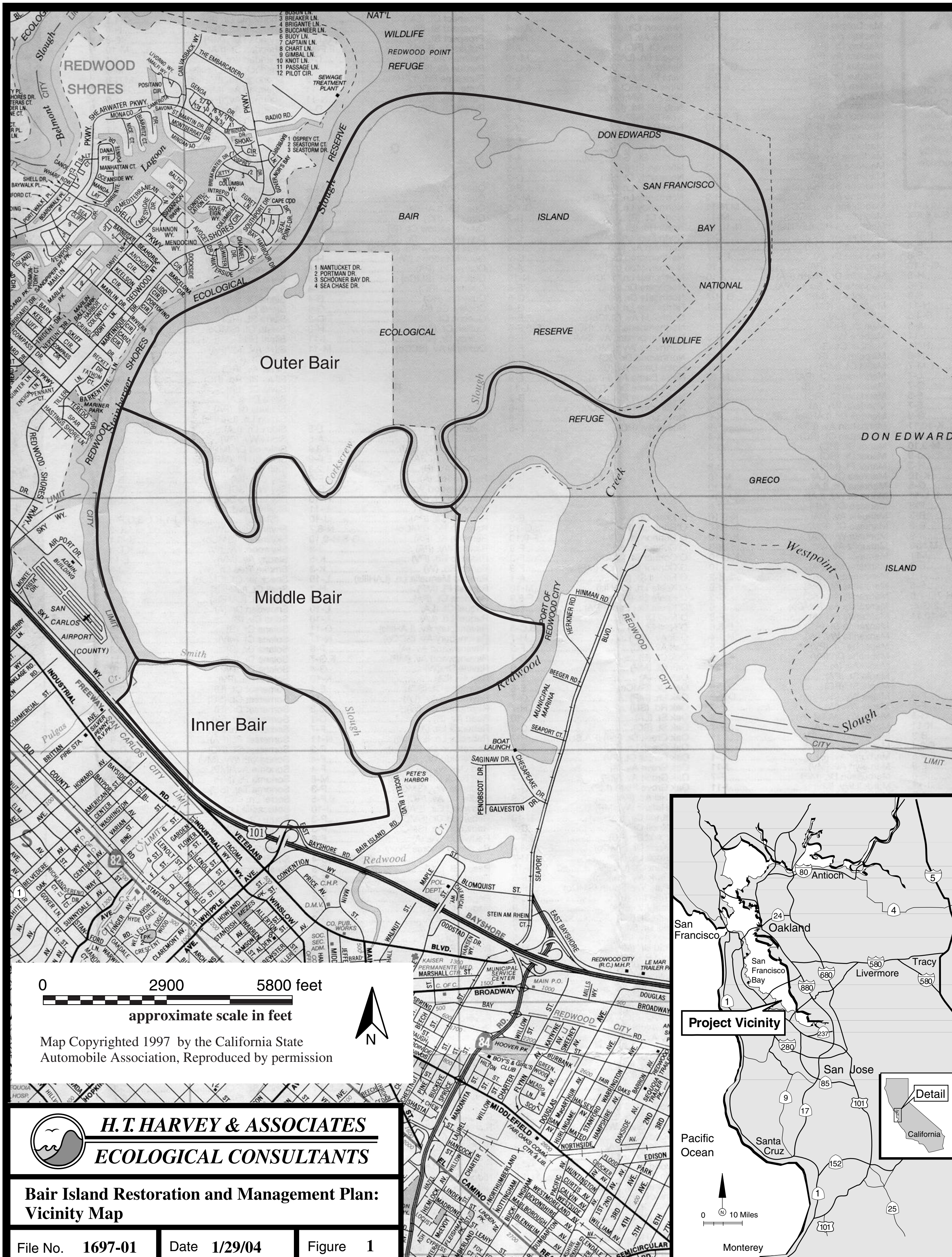
APPENDIX A.
REPORT FIGURES



H.T. HARVEY & ASSOCIATES
ECOLOGICAL CONSULTANTS

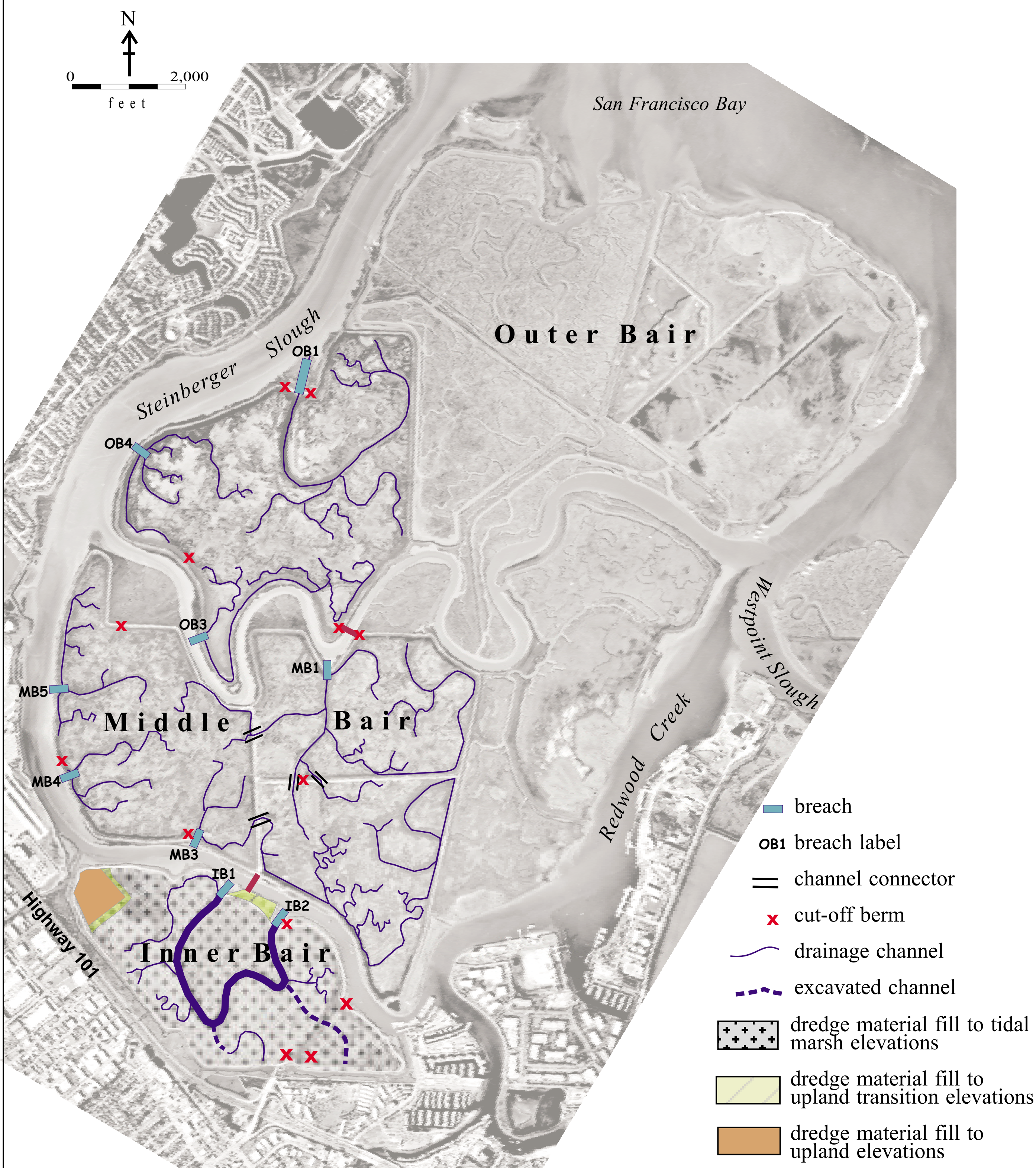
Bair Island Restoration and Management Plan: Vicinity Map

File No. 1697-01	Date 1/29/04	Figure 1

figure 2

Bair Island

Recommended Alternative: Restoration Plan



See figure 19 for Inner Bair detail

Basemap: aerial photograph (2/18/00)

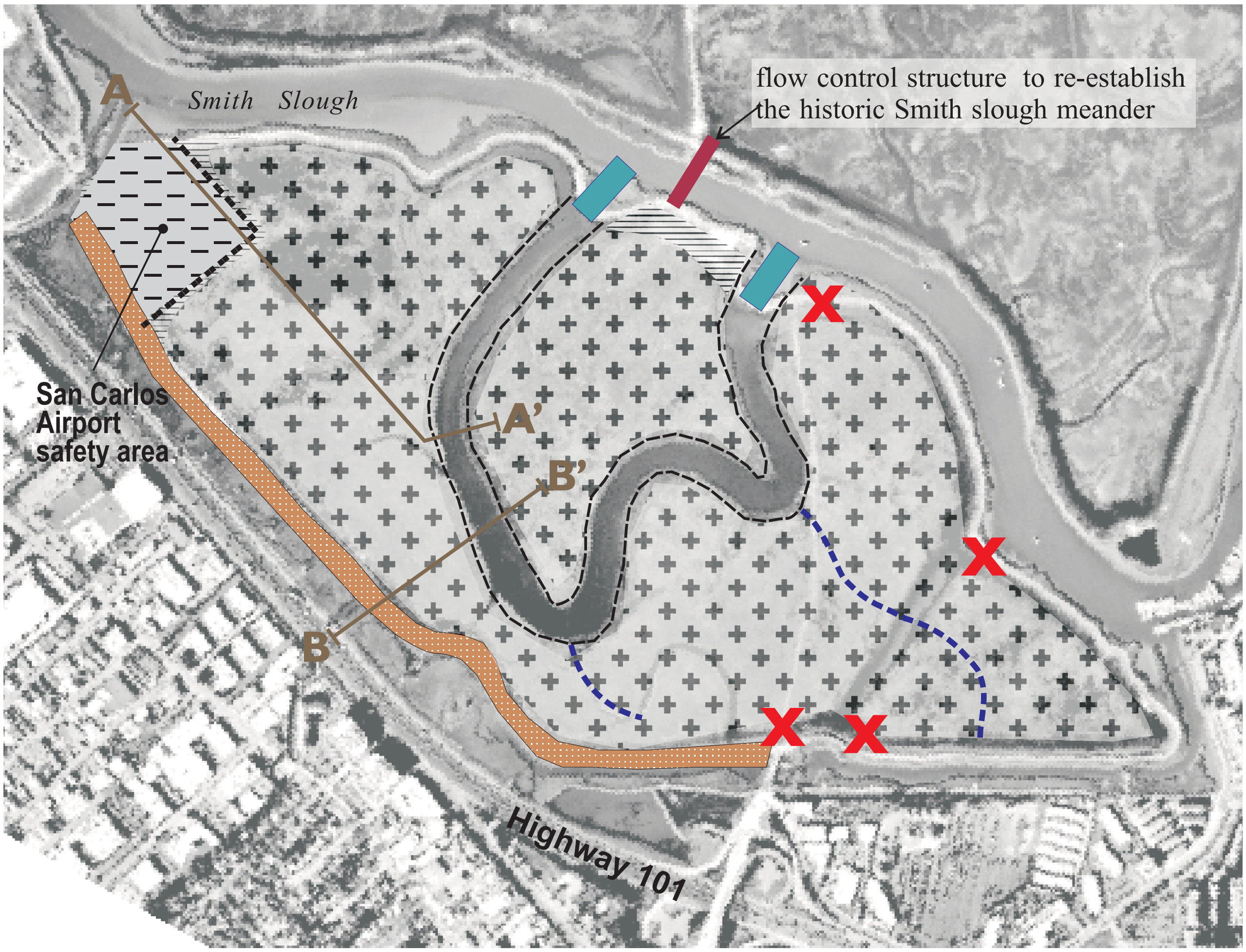
1413 \ nov13, 02 \ fig 14 Rest_Plan.cdr

PWA

figure 3

Bair Island

Recommended Alternative: Restoration Plan Inner Bair Detail



dredge material fill to upland elevations

dredge material fill to upland transition elevations

dredged material fill to tidal marsh elevations

San Carlos Airport safety zone levee

dredged material placement berms

SBSA sewer line levee

breach

cut-off berm

excavated channel

N

feet

0 1,000 2,000

Note: See figure 17 for Transects A-A' and B-B'

PWA

1413 nov 2000\fig3Inner BairDetL.cdr

figure 4

Bair Island

Recommended Alternative: Long-Term Conditions

Basemap: aerial photograph (2/18/00)

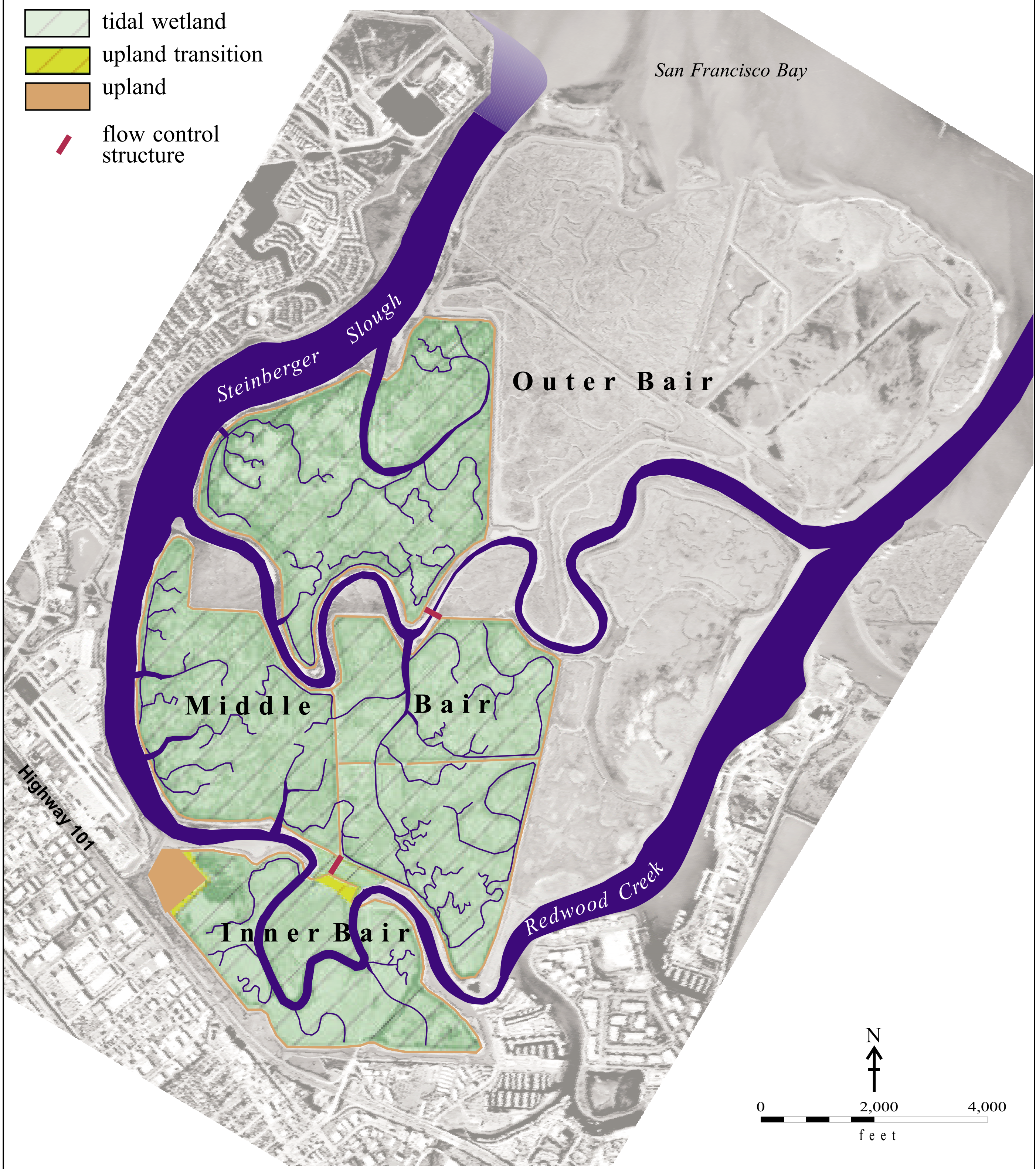
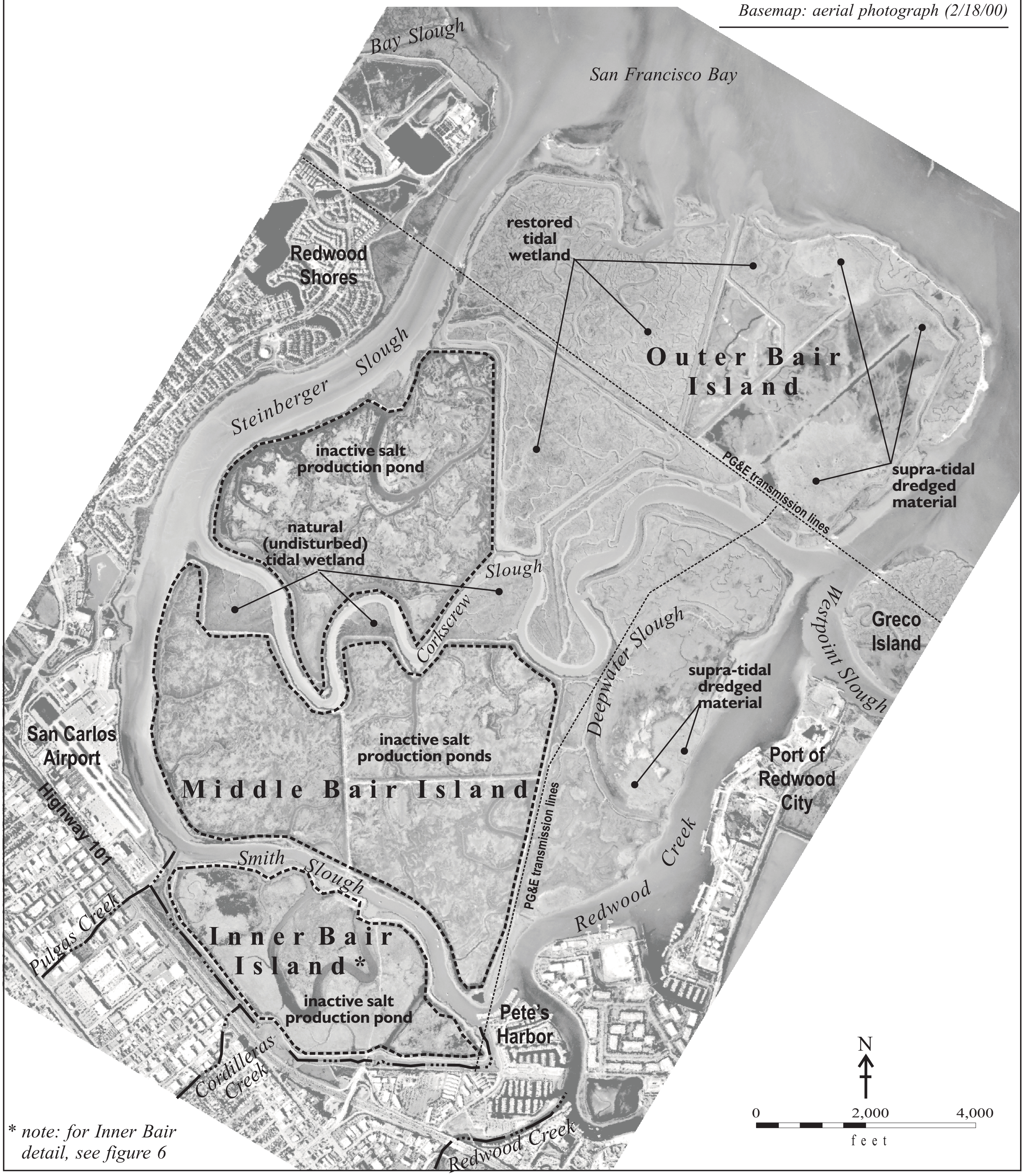


figure 5

Bair Island
Existing Conditions

Basemap: aerial photograph (2/18/00)



* *note: for Inner Bair detail, see figure 6*

1413 \ R&M Plan Aug02\ ExistingCond photo2.cdr

PWA

figure 6

Bair Island

Existing Conditions, Inner Bair Detail

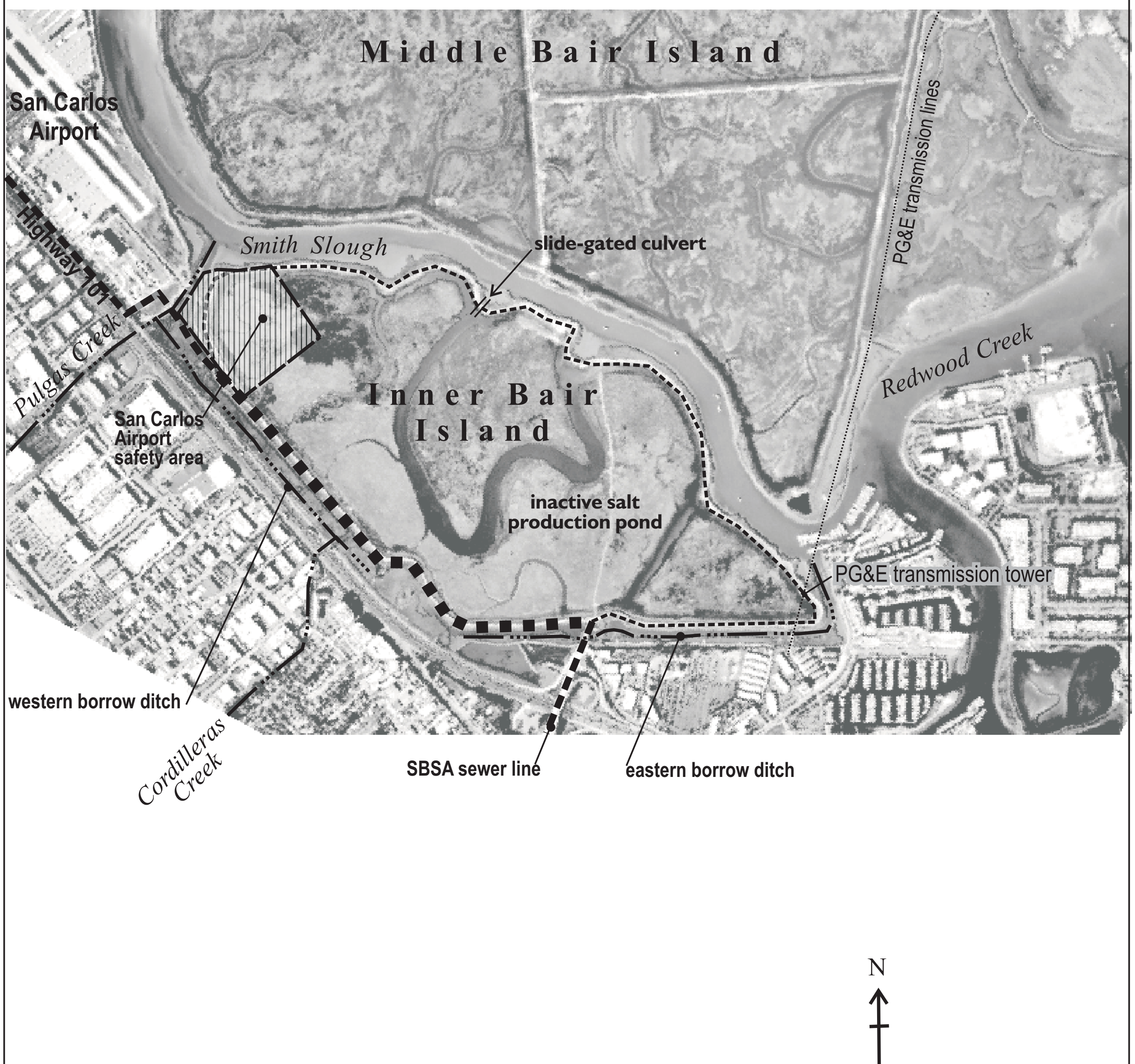
Basemap: aerial photograph (2/18/00)

channels

levees

SBSA sewer line

SBSA sewer line under levee



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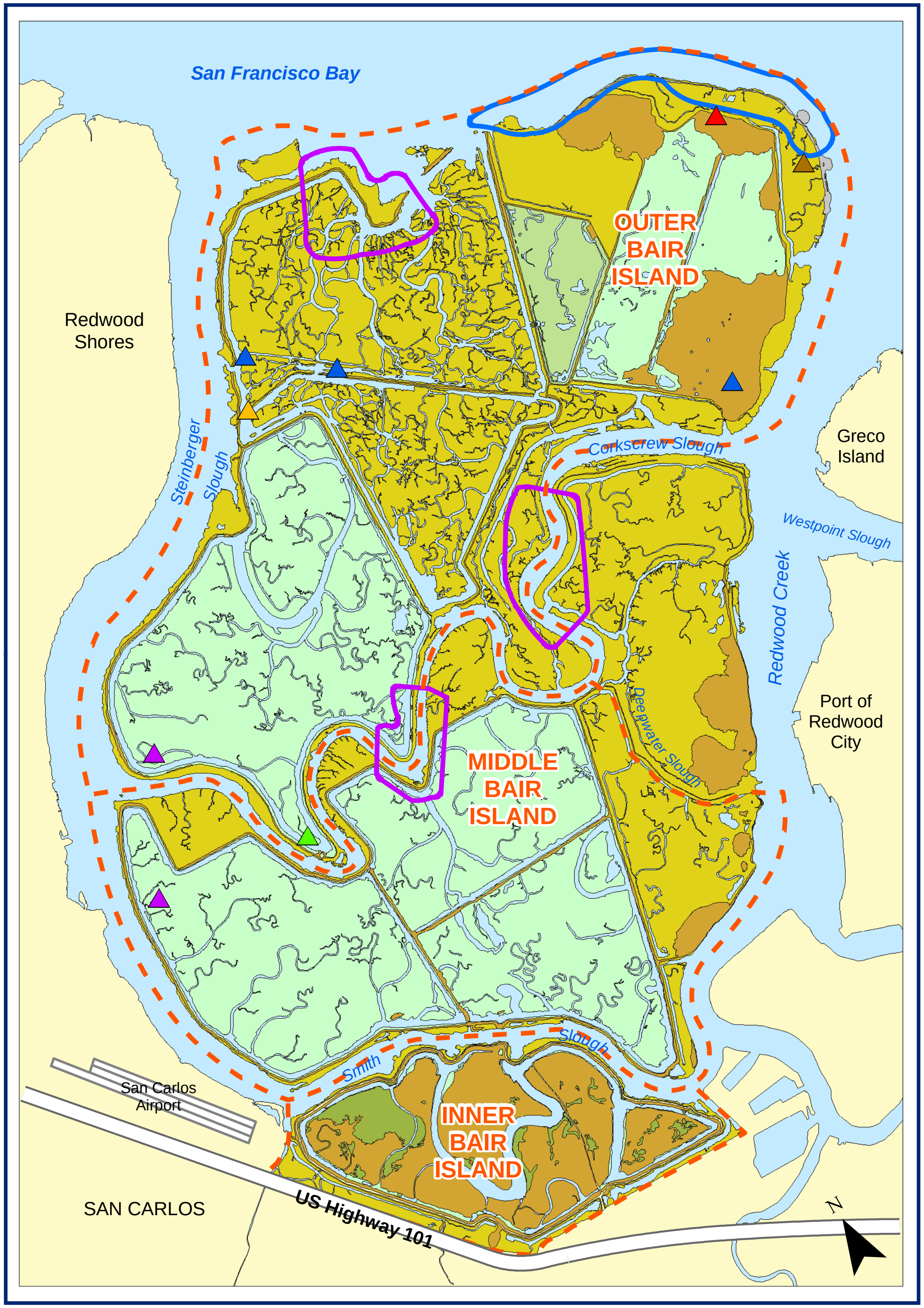
Bair Island Restoration Project
Figure 7: Habitat Map (1/29/04)



Project Boundaries

LOCATIONS OF WILDLIFE USE:

- Existing Brown Pelican Roost
- Existing Double-crested Cormorant/ Great Blue Heron Nests
- Existing White-tailed Kite Nest
- Potential Caspian Tern Colony
- Potential Forster's Tern/ American Avocet Colonies
- Previous Forster's Tern Colony
- Harbor Seal Haul-out Location
- Potential Snowy Plover Nesting Habitat

EXISTING HABITATS (2000):

Aquatic

Developed

INNER BAIR ISLAND: 8.47 acres MIDDLE BAIR ISLAND: 0.00 acres OUTER BAIR ISLAND: 0.00 acres

Shell Mounds

INNER BAIR ISLAND: 0.00 acres MIDDLE BAIR ISLAND: 0.00 acres OUTER BAIR ISLAND: 5.63 acres

Ruderal Upland

INNER BAIR ISLAND: 187.89 acres MIDDLE BAIR ISLAND: 38.02 acres OUTER BAIR ISLAND: 141.45 acres

Diked Salt Marsh

INNER BAIR ISLAND: 9.06 acres MIDDLE BAIR ISLAND: 553.64 acres OUTER BAIR ISLAND: 468.90 acres

Muted Salt Marsh

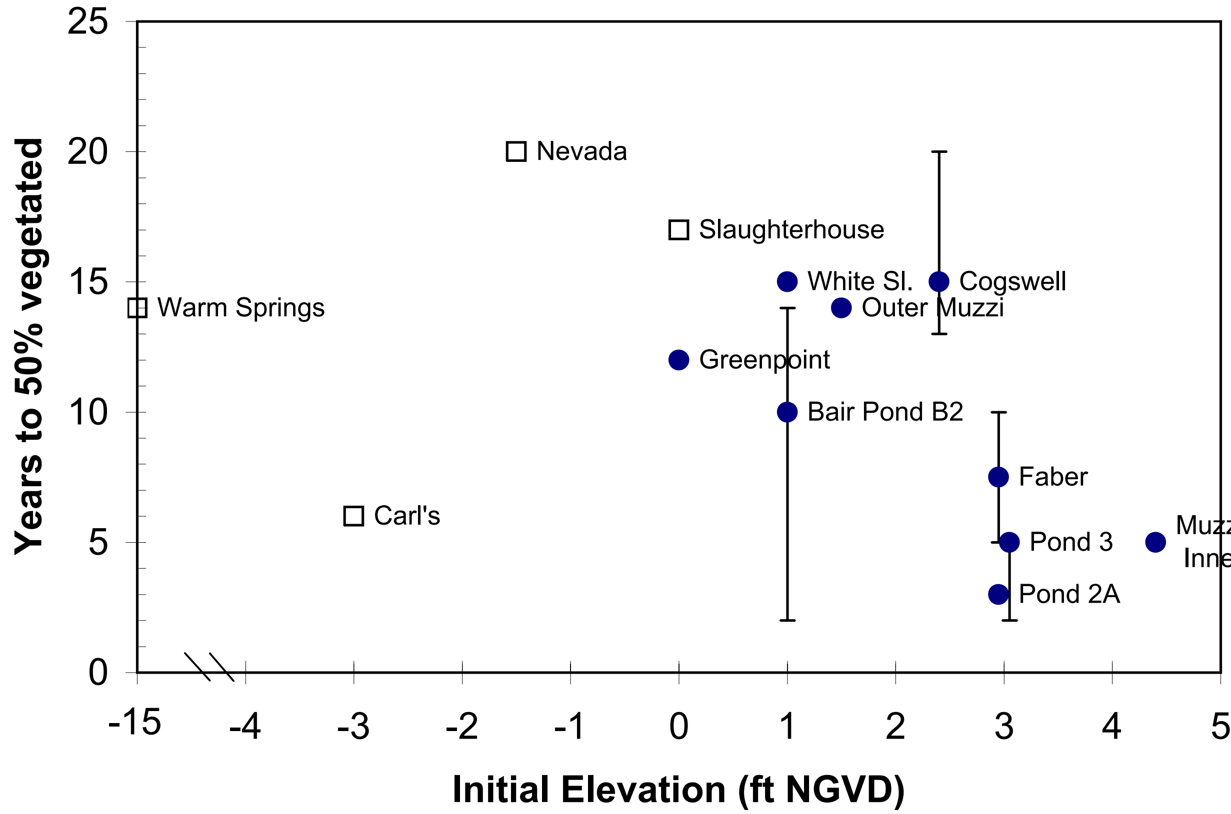
INNER BAIR ISLAND: 0.00 acres MIDDLE BAIR ISLAND: 0.00 acres OUTER BAIR ISLAND: 51.77 acres

Seasonally Ponded Wetland

INNER BAIR ISLAND: 32.82 acres MIDDLE BAIR ISLAND: 0.00 acres OUTER BAIR ISLAND: 0.00 acres

Tidal Salt Marsh

INNER BAIR ISLAND: 36.90 acres MIDDLE BAIR ISLAND: 192.54 acres OUTER BAIR ISLAND: 647.13 acres



● Age when 50% vegetated

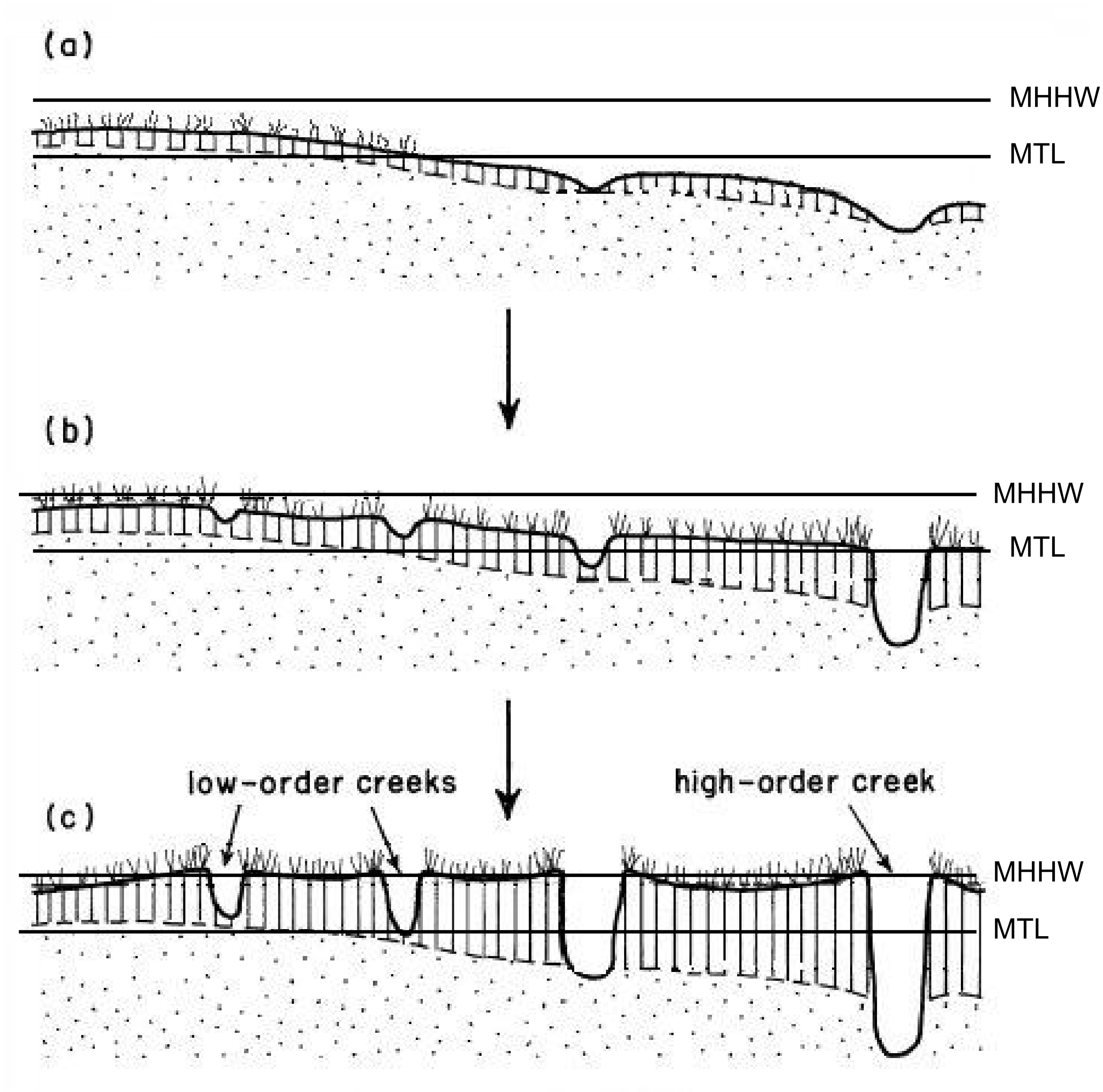
□ Current age if not vegetated (as of Year 2000)

Note: Symbols show most likely estimate; error bars show range.

figure 8

Number of Years for marshplain vegetation to establish versus initial elevation

PWA



A. Young marsh, emergent vegetation & intertidal mudflat
B. Developing marsh, vegetation colonization & channel formation
C. Mature marsh, vegetated marsh plain & channel drainage system

MHHW = mean higher high water
MTL = mean tide level

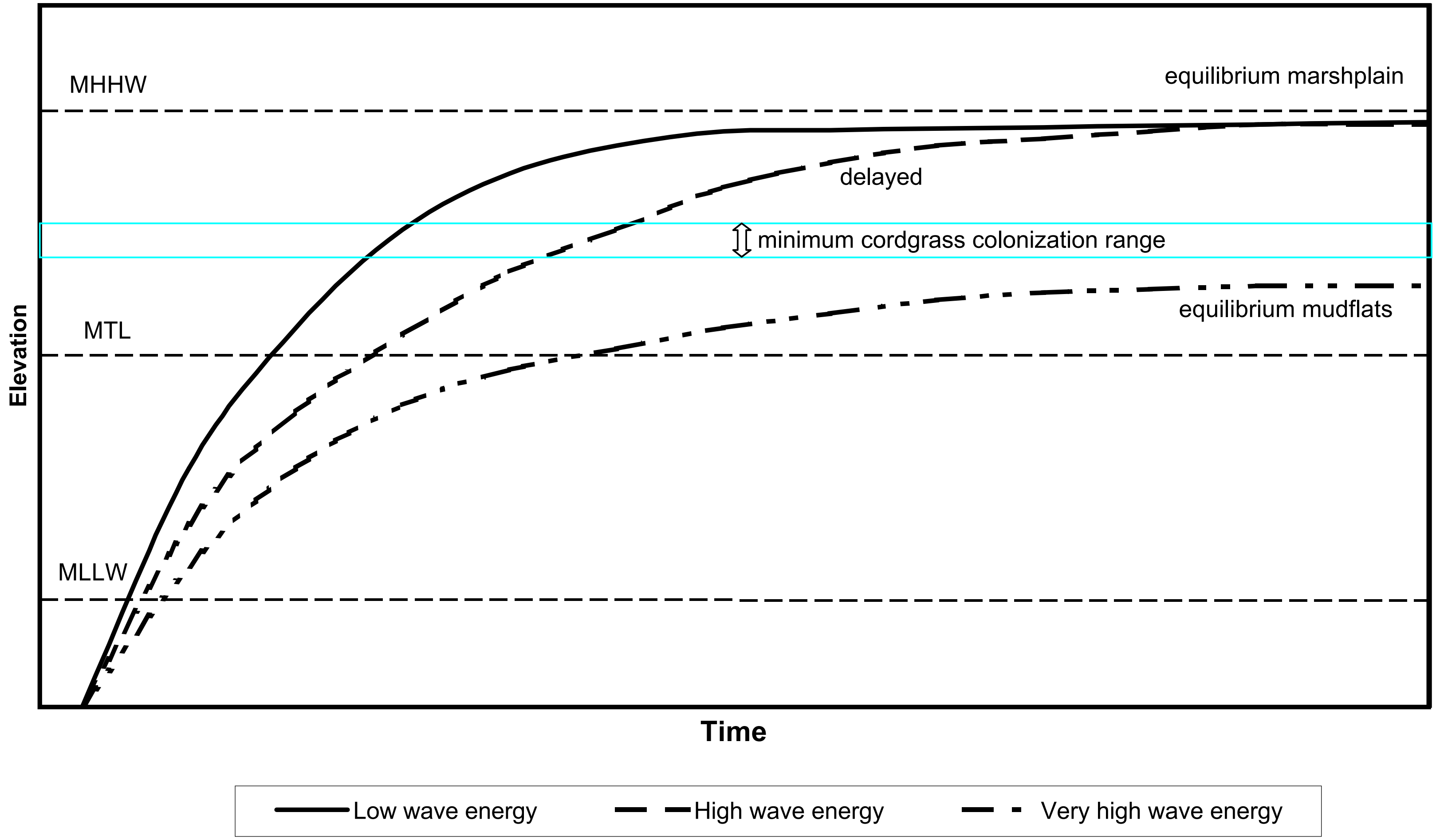
figure 9

Bair Island Restorartion

Schematic of Marsh Evolution

PWA #1591

PWA



Note:
MHHW: Mean Higher High Water
MTL: Mean Tide Level
MLLW: Mean Lower Low Water

figure 10

Tidal marshplain evolution with time since breaching

PWA

PWA #:1413-11

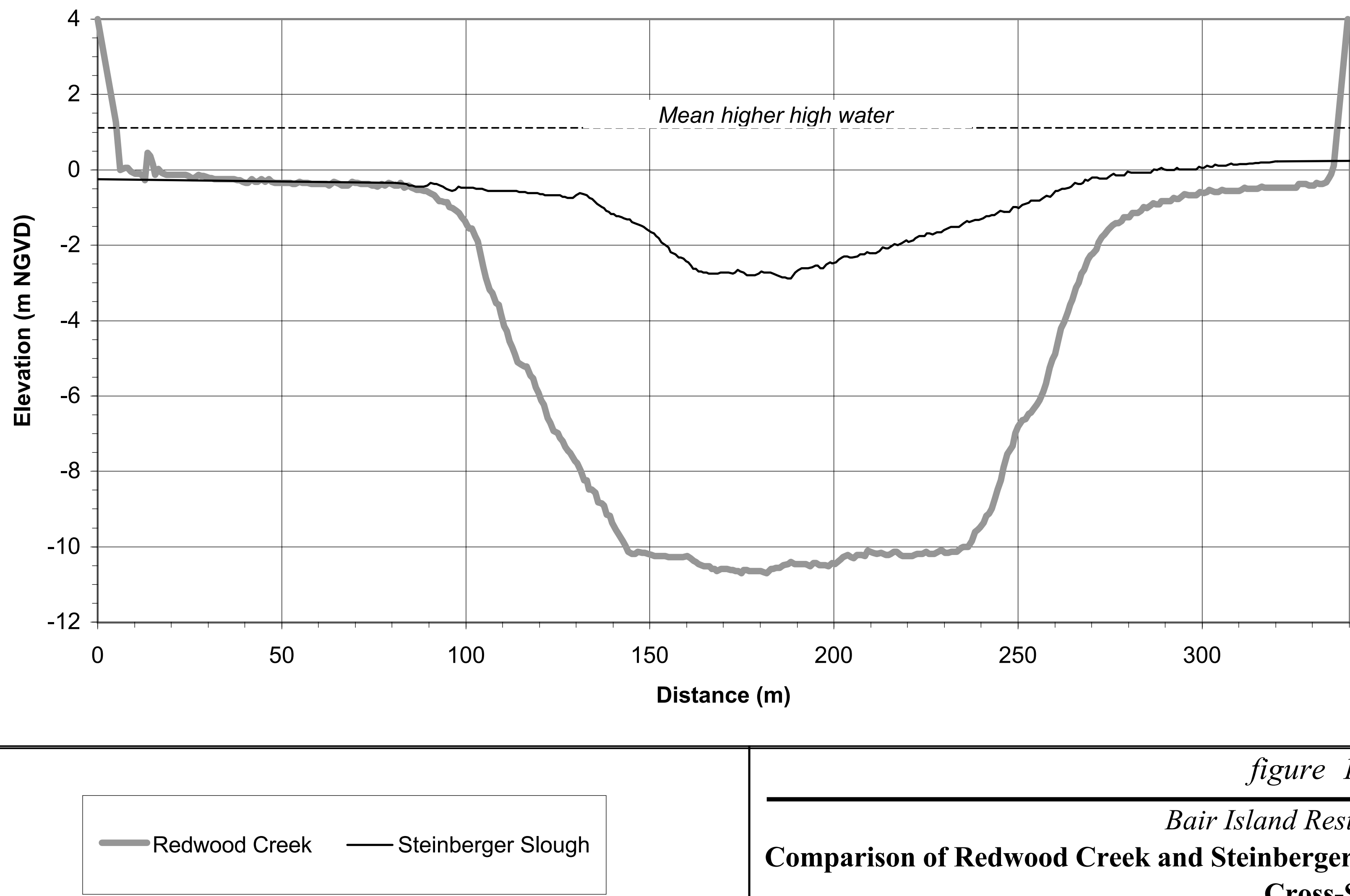


figure 11

Bair Island Restoration

Comparison of Redwood Creek and Steinberger Slough Cross-Sections

PWA

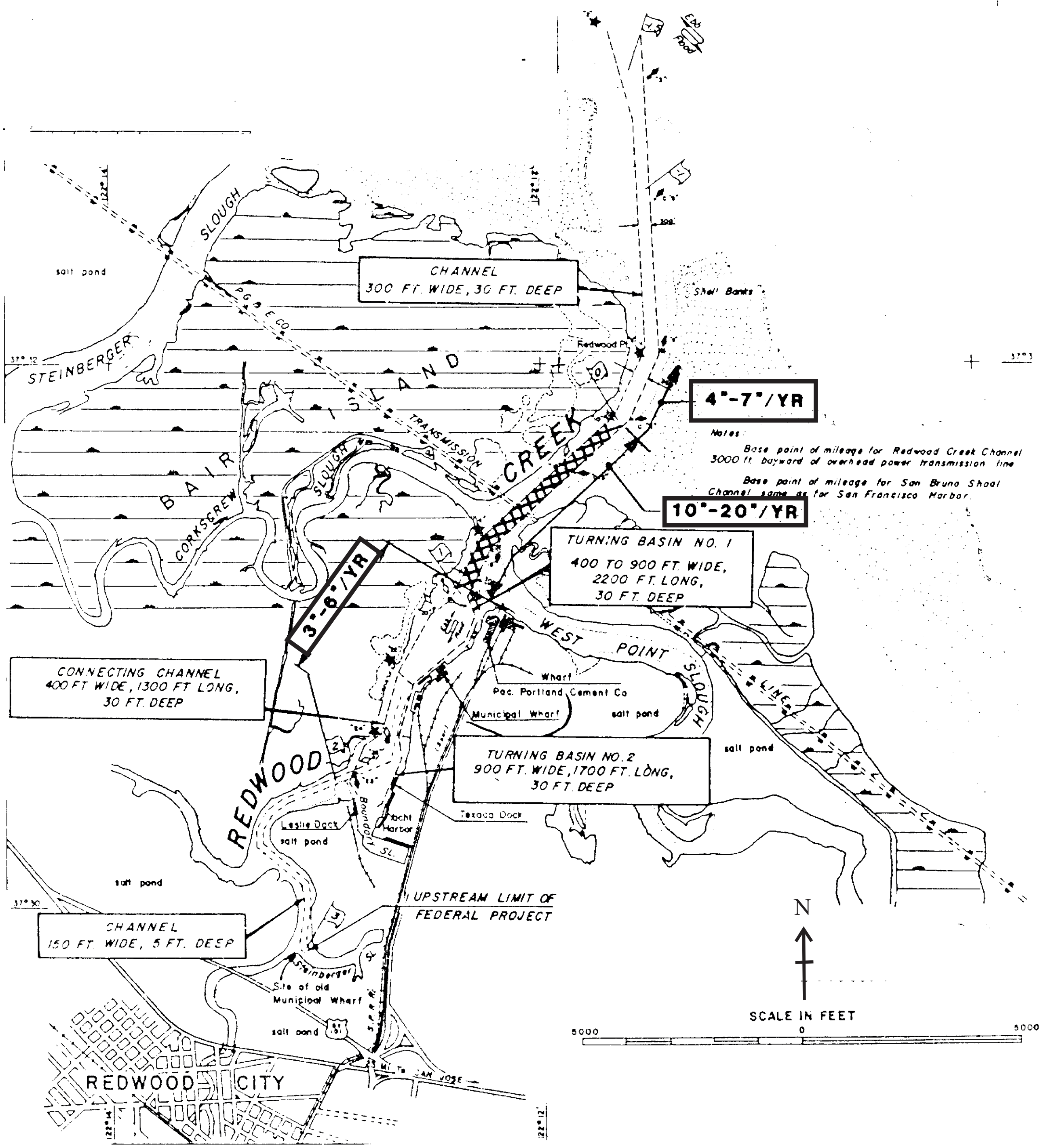
PWA #:1413

figure 12

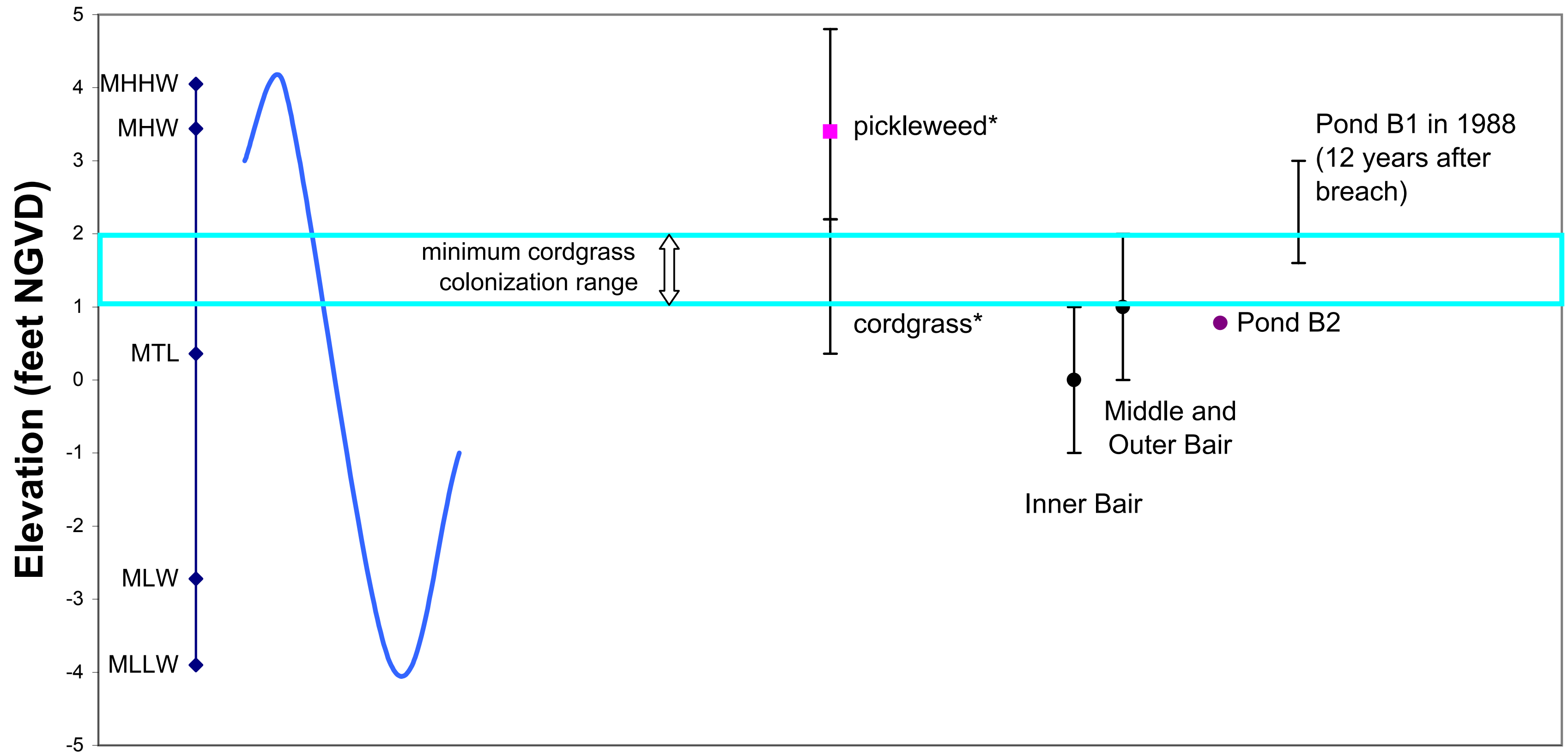
Bair Island
Redwood Creek Shipping Channel
Average Siltation Rates

source: USACE (1972)

= location where significant shoaling occurs



PWA



* elevation range for natural marsh areas of Bair Island

Note: MHHW = mean higher high water; MHW = mean high water; MTL = mean tide level; MLW = mean low water; MLLW = mean lower low water.

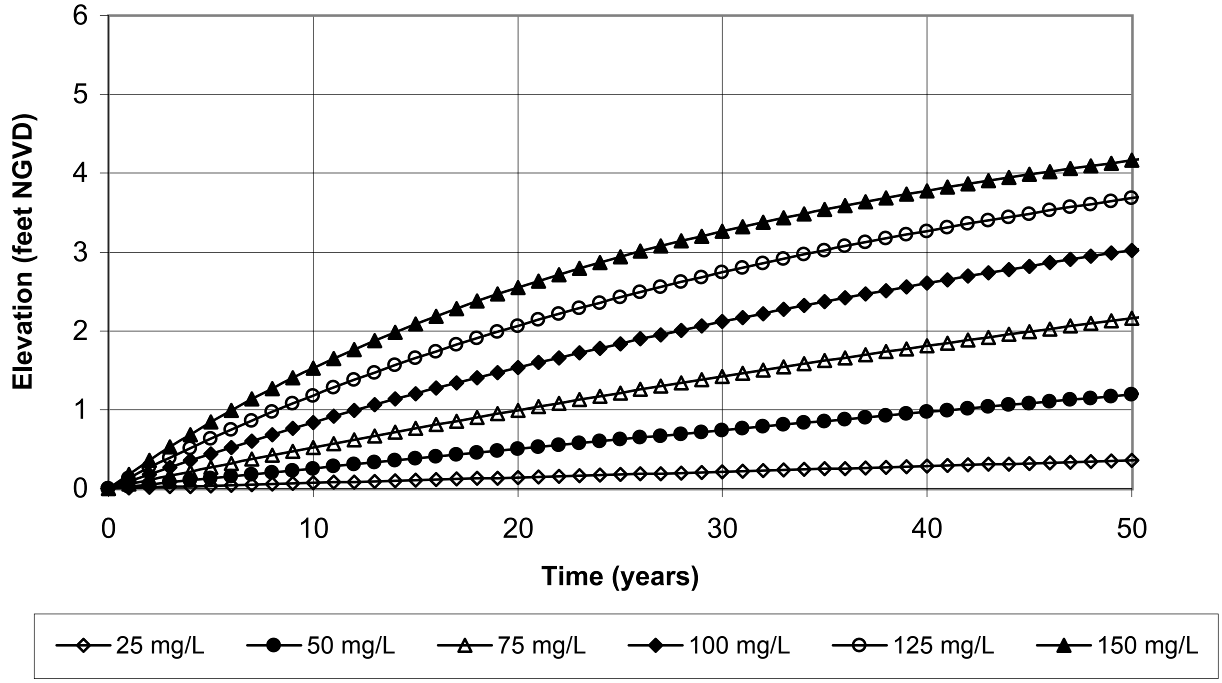
figure 13

Bair Island Restoration

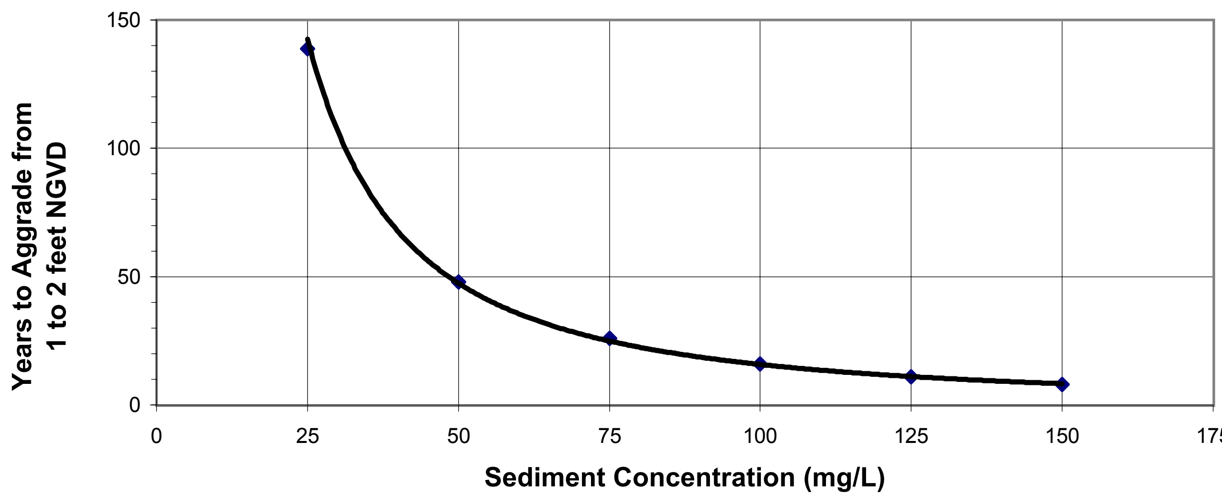
Marshplain Elevations Relative to Tides and Vegetation Ranges

PWA | PWA#: 1413

1413_R&MAug02_figs_v2.xls fig13 8/9/2002



a. Sedimentation Curves for Various Suspended Sediment Concentrations



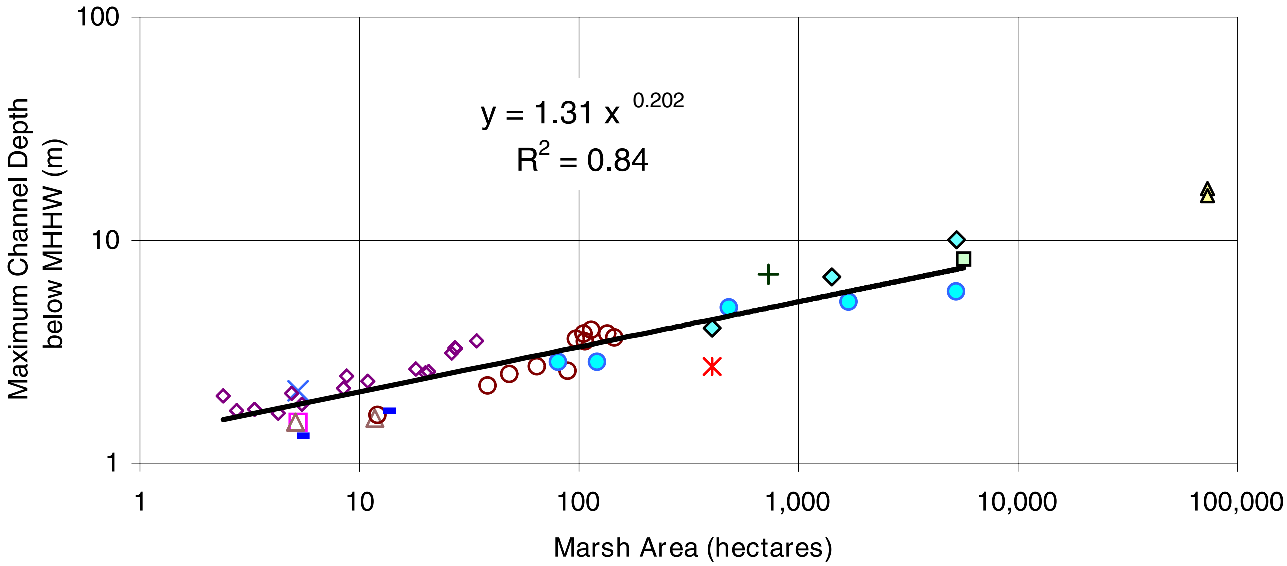
b. Time for Sedimentation from 1 to 2 Feet NGVD vs Suspended Sediment Concentration

Note:
dry density of inorganic material = 550 kg/m3 (consolidated conditions)
Sea level rise = 0.5 foot/50 years
Mean monthly tide from Redwood Creek Channel Marker 8

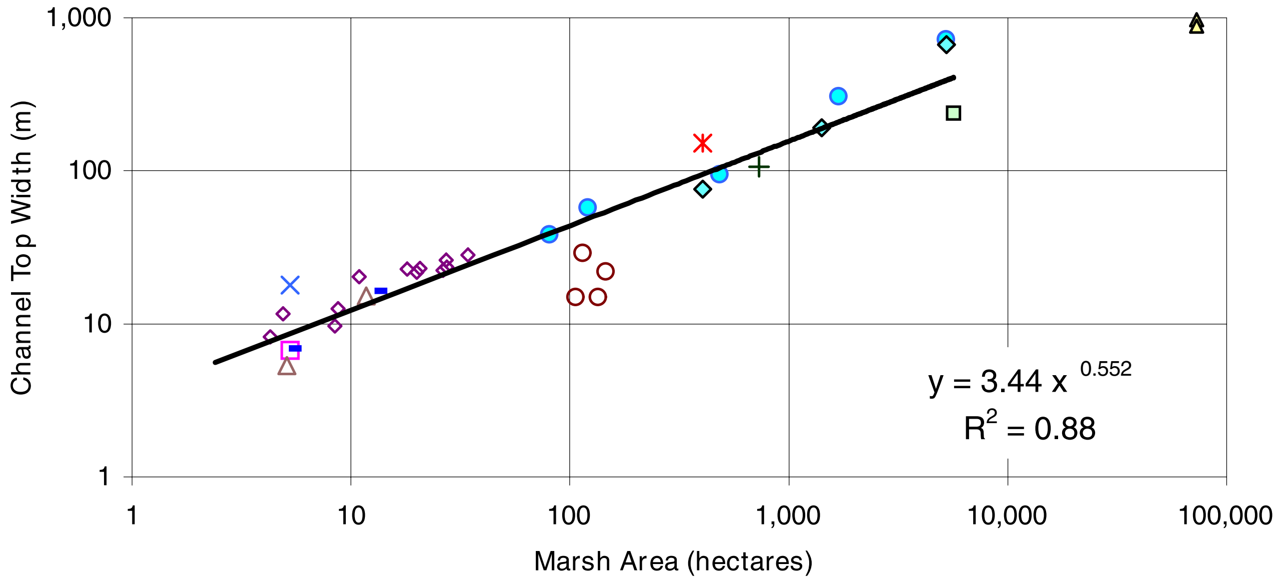
figure 14

Long-Term Sedimentation Variation with Sediment Supply

PWA



a. Channel depth as a function of marsh area.



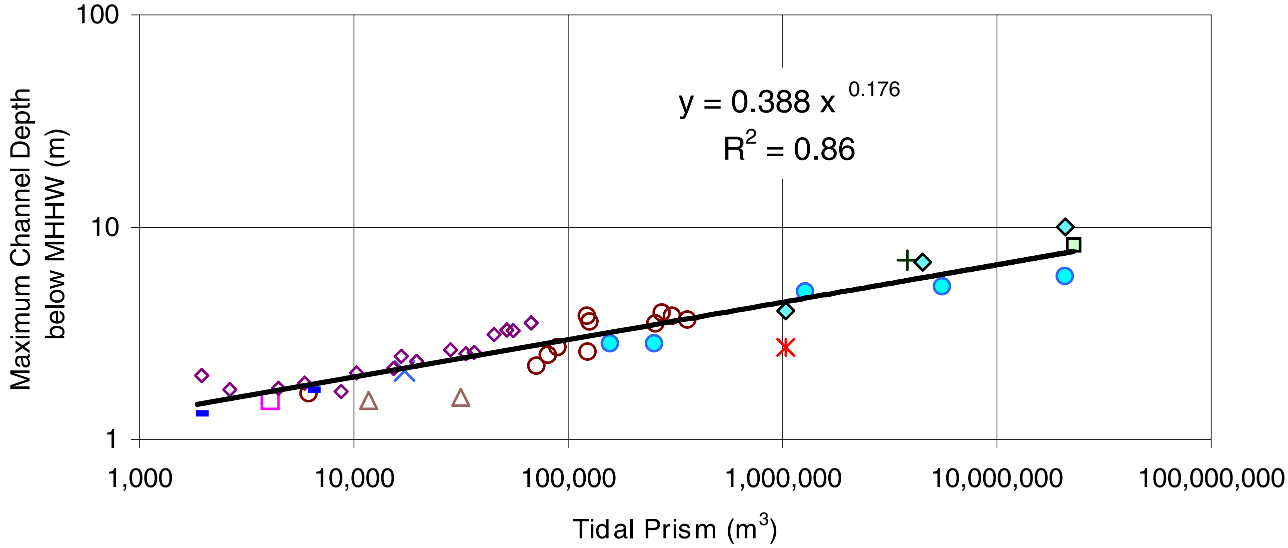
b. Channel width as a function of marsh area.

□ China Camp Marsh	△ Heerdt Marsh
× Laumeister Tract	◇ Newark Slough
○ Petaluma Marsh	+ Ravenswood Slough (historic)
- Wildcat Creek	● Petaluma Historic
◆ Napa Historic	■ Sonoma Historic
✳ Gallinas Historic	▲ San Joaquin Historic

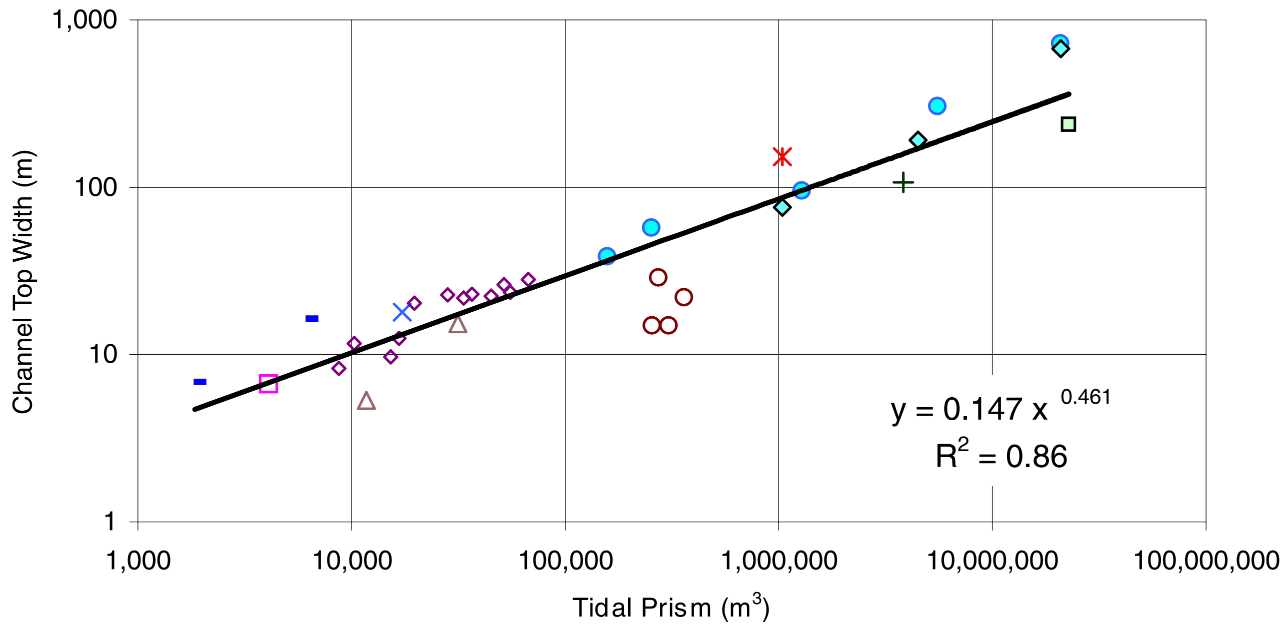
figure 15

Hydraulic Geometry
Marsh Area Relationships

PWA



a. Channel depth as a function of tidal prism.



b. Channel width as a function of tidal prism.

□ China Camp Marsh
△ Heerdt Marsh
× Laumeister Tract
◇ Newark Slough
○ Petaluma Marsh
+ Ravenswood Slough (historic)
- Wildcat Creek
● Petaluma Historic
◆ Napa Historic
□ Sonoma Historic
✱ Gallinas Historic

figure 16

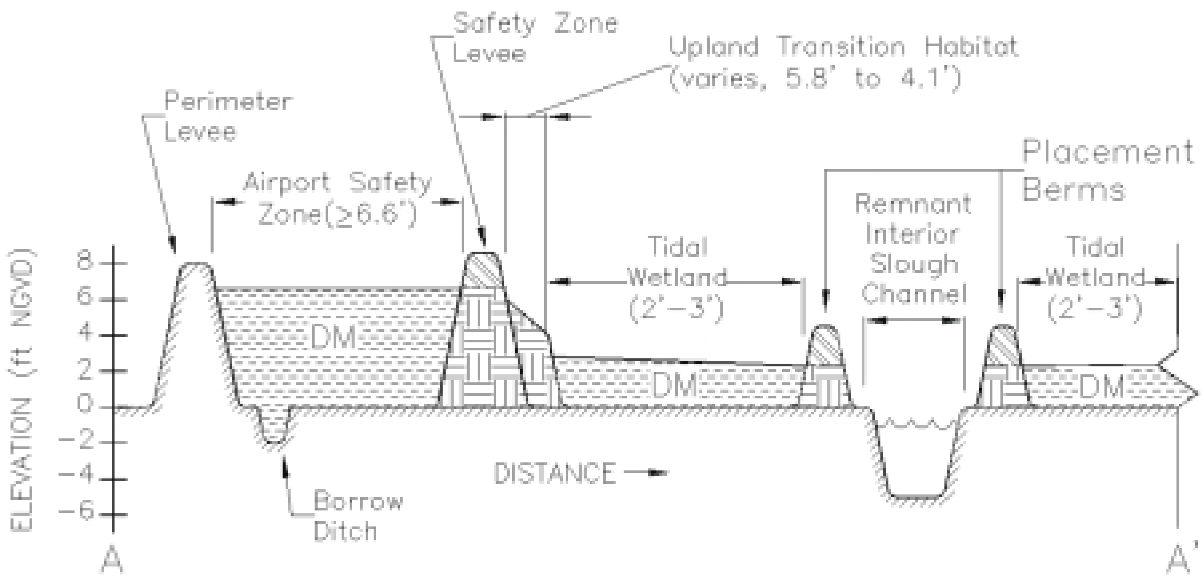
Hydraulic Geometry
Tidal Prism Relationships

PWA

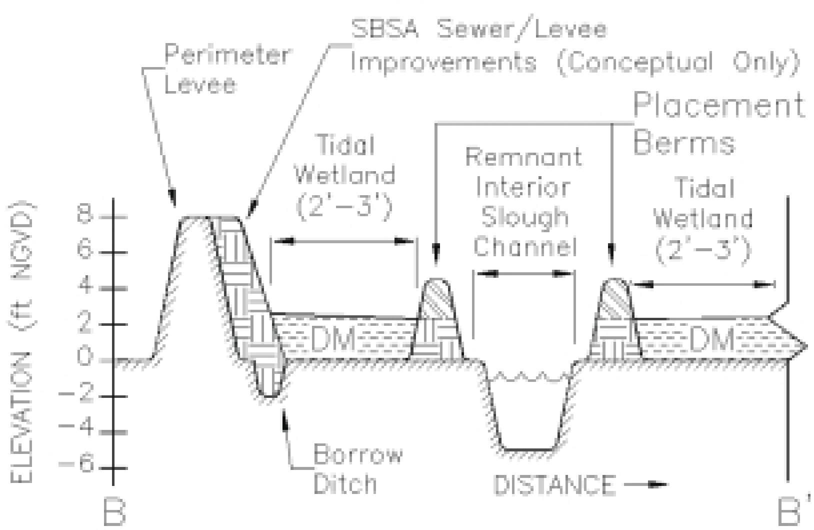
figure 17

Bair Island Restoration

Transects A and B from Inner Bair Detail



TRANSECT A–A' (NTS)



TRANSECT B–B' (NTS)

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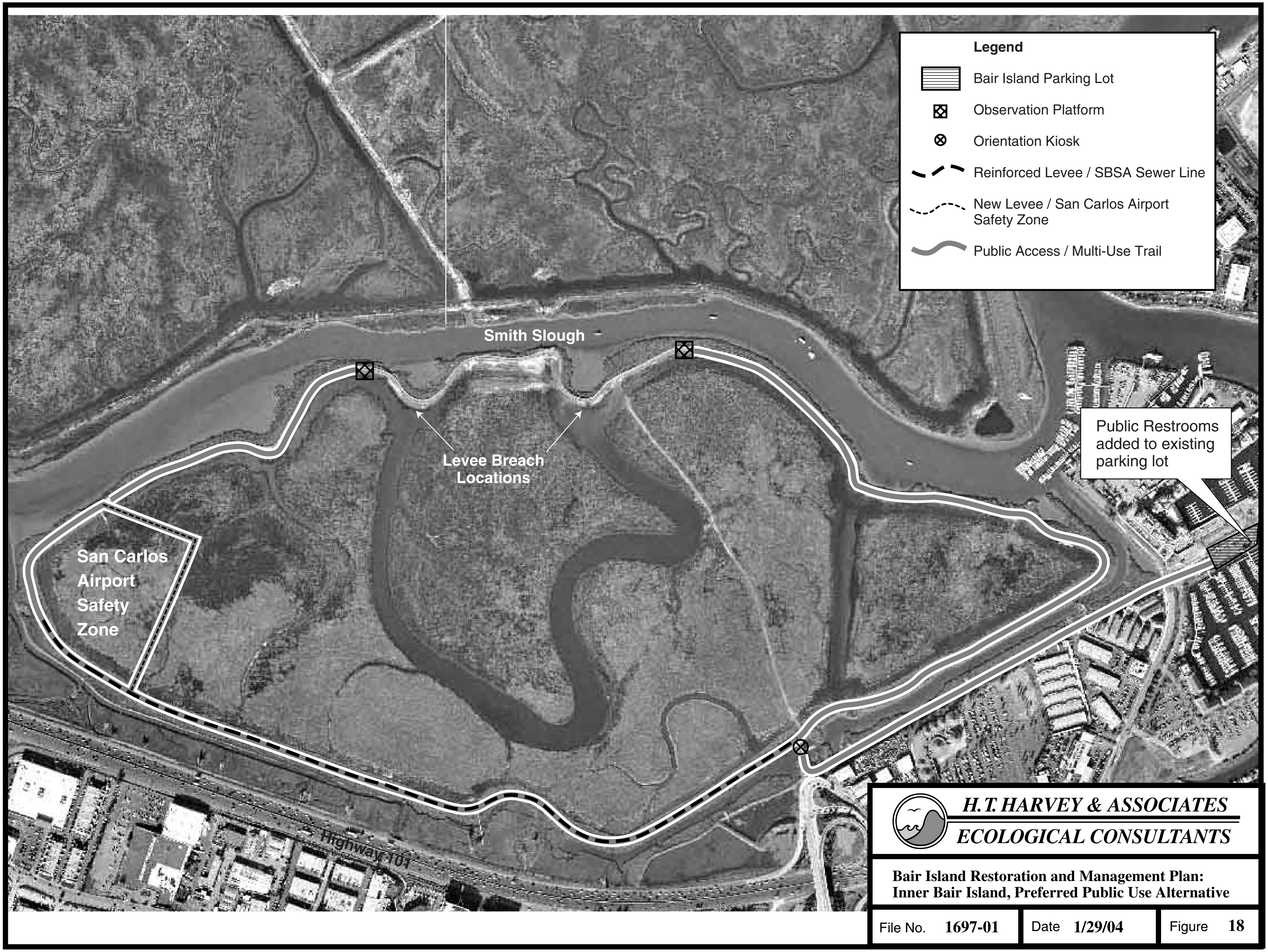


Bair Island Restoration and Management Plan: Inner Bair Island, Preferred Public Use Alternative

File No. 1697-01 | Date 1/29/04 | Figure 18

APPENDIX B.
HYDRODYNAMIC MODELING

BAIR ISLAND RESTORATION AND MANAGEMENT PLAN

APPENDIX B: HYDRODYNAMIC AND SEDIMENT TRANSPORT MODELING

1. INTRODUCTION

Numerical modeling was conducted by PWA to assist in the development and evaluation of restoration alternatives at Bair Island. This modeling effort included hydrodynamic simulations of water levels and currents, as well as cohesive sediment transport (CST) modeling. The numerical model proved useful in identifying constraints associated with the restoration plan and developing modifications to the restoration design. The following constraints were identified through model runs and significantly affected design development:

1. Potential for increased sedimentation in the Redwood Creek Shipping Channel,
2. Potential for increased tidal currents at Pete's Harbor, and
3. Sufficient sediment supply to the breached islands.

This appendix summarizes the modeling effort and presents key findings from the analysis. A description of the numerical schemes employed in the hydrodynamic and sediment transport models are given.

2. CONCLUSIONS AND RECOMMENDATIONS

- A series of numerical simulations was carried out in order to refine the restoration alternative, and led to the August 2002 recommended restoration plan shown in Figure 2 of the main text and described in the main body of this report. Project elements include construction of a flow constriction along Corkscrew Slough, re-establishment of the historic meander along Smith Slough, and breaching only to the Steinberger Slough part of the system. These elements are intended to minimize any increase of tidal prism conveyed through Redwood Creek thereby avoiding impacts to the shipping channel and Pete's Outer Harbor (see below). Model results indicate that under this restoration configuration the tidal prism after breaching is approximately equal to existing conditions, and that impacts to Pete's Harbor and Redwood Creek will be minimal. This configuration also improves estuarine sediment supply to the interior sections of the slough network through Steinberger Slough.

- The Redwood Creek tidal channel is greatly oversized due to regular dredging needed to maintain the deep-draft navigation to the Port of Redwood City. Because it is hydraulically more efficient, Redwood Creek has captured a large portion of the tidal prism that would normally scour Steinberger Slough. This has lead to substantial shoaling along Steinberger Slough.

- Numerical simulation indicates that without flow control structures designed to re-route the flow to Steinberger Slough, most of the new tidal prism created by breaching of Middle and Inner Bair Islands will be supplied through Redwood Creek. Increases in the amount of tidal flow passing through Redwood Creek will lead to additional sedimentation in the shipping channel and increased frequency of dredging. Hydrodynamic modeling indicates that under the preferred restoration alternative, the tidal prism and velocity along the shipping channel will remain similar to existing conditions and prevent additional shoaling along Redwood Creek.

- Under existing conditions, tidal currents at Pete's Outer Harbor are at the high end of the range generally considered acceptable for boat navigation. Peak velocities are about 0.4 m/sec. Hydrodynamic modeling indicates that without any realignment of the existing flow routes with flow control structures, restoration of Middle and Inner Bair Islands to tidal action may triple peak tidal currents at Pete's Outer Harbor. This is primarily due to the fact that much of the tidal prism developed after breaching of the islands will be conveyed through Smith Slough and Redwood Creek and will pass through Pete's Outer Harbor. Hydrodynamic modeling indicates that peak tidal currents will remain at about existing levels with re-establishment of the historic Smith Slough meander and a channel block along Corkscrew Slough.

- Hydrodynamic modeling indicates that most of the tidal prism associated with the recommended restoration plan will be routed through Steinberger Slough. Besides minimizing potential project-related impacts to Pete's Outer Harbor and Redwood Creek, this routing will increase the scour potential along Steinberger Slough and reverse the shoaling observed over the past decades. Although the major source of sediment for marshplain establishment will come from the Bay, some of the material eroded along Steinberger Slough is also expected to deposit in the restored islands.

- Under existing conditions, most of the water discharged during flood events from Pulgas and Cordilleras Creeks is ultimately routed through Redwood Creek and into the Bay. Preliminary model simulations indicate that flow re-alignment designed to address the Pete's Harbor velocity and Port sedimentation issues will also restrict conveyance of flood discharges from the watershed. This will need to be addressed in the design.

- Numerical modeling shows that low tide elevations at the confluence of Steinberger and Smith Sloughs are elevated. Low-tide drainage will improve as Steinberger Slough scours. Although results from the modeled long-term scenario indicate that the tidal signal remains muted, actual drainage is likely to be better as the actual equilibrium geometry may be different than that assumed in the model.

3. DISCUSSION OF THE NUMERICAL MODEL

The flowing sections describe the numerical schemes employed in the model, selection of boundary data, and schematization of the slough-island system.

3.1 DESCRIPTION OF THE NUMERICAL SCHEMES

MIKE 11 is a software package for the simulation of flows, water quality and sediment transport in water bodies that are one-dimensional in nature. Although the actual flow is three-dimensional, most of the movement of water in the tidal slough network follows the longitudinal axis of the channels. Therefore, application of a 1-D model was used to characterize the general flow patterns, and efficiencies in the one-dimensional scheme allowed for a variety of modifications to be tested during the development of the restoration design.

Two modules were employed in the current modeling effort: the hydrodynamic (HD) and cohesive sediment transport (CST) modules. The numerical schemes of each of these modules is described below.

3.1.1 Hydrodynamic (HD) Module

The hydrodynamic module of MIKE 11 HD solves the vertically integrated equations of conservation of continuity and momentum (the 'Saint Venant' equations), based on the following assumptions:

- the water is incompressible and homogeneous;
- the bottom-slope is small;
- the wave lengths are large compared to the water depth. This ensures that vertical accelerations can be neglected and a hydrostatic pressure gradient may be assumed; and
- the flow is sub-critical (super-critical flow is modeled, but more restrictive conditions must be applied).

Discharge and water level are reported at computational points throughout the model domain. Additional parameters such as bed shear stress and cross-sectionally averaged velocity are also reported. It is important to note that since MIKE 11 is a one-dimensional model, these quantities are sectionally-averaged and may differ from point measurements collected from field surveys. Further details of the numerical scheme may be found in the MIKE 11 Reference Manual (DHI, 2001).

3.1.2 Cohesive Sediment Transport (CST) Module

The transport of suspended sediment is modeled with the advection-dispersion equation due to the low settling velocities of fine sediments. The processes of erosion and deposition are modeled as source and sink terms, respectively, in the advection-dispersion equation. The erosion rate depends on local hydraulic conditions whereas the deposition rate additionally depends on the concentration of suspended sediment. The subsections below describe how the processes of settling, deposition, erosion and consolidation are implemented in the CST model.

Estuarial sediment beds are typically composed of flow-deposited cohesive material and occur in one of three states: stationary suspension; partially consolidated beds; and fully-consolidated beds. Initial model calibration was carried out using a single-layer homogeneous consolidated bed model. Re-calibration using a multi-layer model in order to account for vertical variations in density and shear strength found in layered beds was originally expected to improve the fit between simulated and measured SSC. However, additional hydrodynamic modeling was substituted for re-calibration of the sediment transport model and changes in sedimentation were inferred from surrogate hydrodynamic parameters (see Section 4 for further discussion).

3.1.2.1 Settling

The settling velocity of sediment flocs in the deposition equation is dependent on the suspended sediment concentration. In saline water, attractive forces cause sediment particles to "stick together" (i.e. flocculate) and form flocs. Below a certain threshold concentration (approximately 10,000 mg/L), the settling velocity of flocs increases with concentration. For concentrations above this threshold, the settling velocity of flocs is reduced by the upward flow of displaced liquid. This phenomena is called hindered settling.

The more advanced multi-layer MIKE 11 CST model uses two different flow regimes to simulate the settling of sediments, separated by a user-defined suspended sediment concentration that divides flocculating suspensions from suspensions with hindered settling. These two regimes of settling velocity are expressed in the numerical model by:

$w_s = kc^m$ for flocculating suspensions *(c < C-offset)*

$w_s = w_o(1-c)^\gamma$ for hindered-settling suspension *(c > C-offset)*

where,

w_s	= settling velocity
w_o	= free settling velocity of individual flocs
k, m, and γ	= coefficients based empirical data and model calibration
c	= suspended sediment concentration
C-offset	= the concentration above which hindered settling reduces the settling velocity

The single-layer CST model that was applied to the initial calibration has a more simple description of settling. In this model, no flocculation is included in the settling velocity and only one flow regime is allowed (no hindering settling).

3.1.2.2 Deposition

Deposition is modeled as a sink term in the advection-dispersion (AD) equation in MIKE 11 CST, with the rate of deposition given by:

$$S_d = w_s c\left(1 - \frac{\tau_b}{t_{cd}}\right), \quad \text{for } \tau_b \le \tau_{cd}$$

where,

S_d	= The rate of deposition (kg/m^2/s)
w_s	= Mean settling velocity of the suspended particles and sediment flocs (m/s)
c	= Suspended sediment concentration (kg/m^3)
τ_b	= Bed shear stress (N/m^2)
τ_{cd}	= Critical shear stress for deposition (N/m^2).

The bed shear stress is a function of the roughness, water depth and velocity and is computed from the HD model.

3.1.2.3 Erosion

Erosion is modeled as a source term in the advection-dispersion (AD) equation in MIKE 11 CST, with the rate of deposition given by:

$$S_e = E_o\left(\frac{\tau_b}{t_{ce}} - 1\right), \quad \text{for } \tau_b \ge \tau_{ce}$$

where,

S_e	= The rate of erosion (kg/m^2/s)
E_o	= Erosion rate coefficient (kg/m^2/s)
τ_b	= Bed shear stress (N/m^2)
τ_{ce}	= Critical shear stress for erosion (N/m^2).

The critical shear stress for erosion increases with depth for each successive bed layer. The first layer of sediment is the weakest while the bottom-most layer is the strongest or most resistant to erosion.

3.2 DESCRIPTION OF INPUT DATA

Geometric representation of the tidal slough network and restored islands were needed to construct a numerical model of the system. Additionally, boundary data were required to drive the hydrodynamic and sediment transport models, and data from interior locations were used for calibration. The paragraphs below describe the bathymetric, hydrodynamic, and suspended sediment data used in the modeling effort. Much of this data was collected during an extensive field monitoring program by PWA, which is described in detail in a previous memorandum.

3.2.1 Bathymetry and Geometric Representation

Model bathymetry was constructed using a combination of marshplain topography and slough channel hydrography from both existing sources and surveys conducted for this study. Existing topographic information for the site consists of 1981 topographic maps of Inner and Middle Bair Islands (BKFA 1981), 1993 surveys of levee crest elevations on Inner Bair (Bohley Maley Associates, 1993), and surveys conducted for this study. Hydrographic information for the site consists of NOS bathymetric maps (NOS 1995) and field surveys conducted for this study. For the current study, PWA surveyed elevations of marshplain transects and cross-sections of levees, borrow ditches, and channels of Inner, Middle, and Outer Bair Islands in February and March, 2000. Towill surveyed 30 cross-sections of the major slough channels (Redwood Creek, Steinberger Slough, Smith Slough, and Corkscrew Slough) in February 2000. The locations of the both surveys and cross-section plots are included in Appendix E.

Figure B-1 shows the plan view of the slough network included in the model setup, and includes the existing tidal sloughs as well as the interiors of the restored islands. Note that the restored islands are schematically represented in the MIKE11 model by a network of inter-linking prismatic channels. These channels approximately model the drainage area of the restored islands with one-dimensional channels that simulate the resistance and travel time of water over the two-dimensional marshplain. The prismatic channels are sized to accurately represent the tidal prism of each drainage area. The channels are inter-connected within the interior of the restored islands. A prismatic channel connected to one breach can "transfer" water to another channel connected to another breach, such that the flow of water through the interior of the island is simulated. The channel cross-sections have wide gently-sloped marshplains connected to parabolic channels, which model the interior channels and low water drainage. Figure B-2 shows a typical cross-section for a prismatic channel representing the interior of the restored islands.

3.2.2 Tidal Boundary Condition

As part of the PWA field monitoring program, continuous signals of water surface elevation were collected at 6 platforms throughout the slough network (locations shown in Figure B-3) for approximately 30 days by vented pressure transducers (except at Platform 2 where a non-vented pressure transducer was used). The measured data from Platform 1 and 6 were applied as boundary conditions at the bayward limits of Redwood Creek and Steinberger Sloughs for both model calibration and production runs. Week-long time series from these two stations are shown in Figures B-4 and are representative of the longer record. Note the differences in low water drainage, presumably due to the shallow depth of Steinberger Slough.

3.2.3 Suspended Sediment Concentration (SSC)

Continuous point measurements of suspended sediment concentration (SSC) were collected as part of the PWA field data collection program and used during the calibration of the sediment transport model. However, a synthetic time series that was more representative of the long-term average conditions in south bay was applied as boundary conditions for the production runs. The synthetic time series is based on an approach by Schoellhamer (Schoellhamer 2001) and contains a semidiurnal component that is modified by the spring/neap cycle. Long-term mean values of measured SSC collected in the South Bay were used to establish the average values.

3.3 CALIBRATION

Measured water surface elevations, velocity, and SSC data collected during the monitoring program were compared to simulated values for the existing conditions scenario for a range of input parameters to determine the best correlation or model calibration. Bed roughness (Manning's 'n') was adjusted in the hydrodynamic model in order to optimize the match between measured and simulated water levels and velocities. Calibration of the single-layer sediment transport model setting the settling velocity to 0.05 mm/s and varying the parameters in the erosion and deposition expressions. This included the erosion rate coefficient (E_o), critical stresses for the initiation of erosion and deposition (τ_{ce} and τ_{cd}).

3.3.1 Water Surface Elevation

Figures B-5 through B-10 compare simulated and measured water surface elevations at the six monitoring stations throughout Bair Island. In general, the comparison is extremely good with model results tracking the field data in both phase and magnitude. Results from Platform 3 for the seven-day period covered in Figure B-7 are typical. For this case, the root-mean-squared (RMS) difference between modeled and measured water levels is only 71 mm (approximately 2% of the tidal range). Additionally, elevations of high and low waters that are important in determining the extents of tidal inundation are well predicted by the model.

3.3.2 Velocity

Figures B-11 through B-16 compare simulated and measured currents at the monitoring platforms. These plots indicate that currents simulated by the hydrodynamic model match the measured point velocities fairly well. In particular, the modeled and measured currents at Platform 3 have an RMS difference of 0.07 m/sec for the eight-day period shown in Figure B-13. Peak currents play an important role in erosion of bed sediments and are well predicted by the model. For the results shown in Figure B-13 (Platform 3) the peak currents have an RMS difference of 0.04 m/sec (approximately 10% of the peak values).

The measured time-histories were from point current velocities. These were confirmed to be representative of the average velocity through the slough. Discharge and cross-section area from acoustic Doppler current profiler (ADCP) measurements were used to compute the average velocity. These computations indicate that the measured point current measurements are representative of average flows in the slough and can be used to calibrate the vertically- and laterally-averaged flows computed by the model.

3.3.3 Suspended Sediment Concentration (SSC)

Continuous point measurements of suspended sediment concentration (SSC) were made at the each of the 6 platforms for approximately 30 days using OBS instruments and used to calibrate the sediment transport model. However, significant biofouling limited the amount of useful data collected by the OBS instruments over the monitoring period. Figure B-17 shows clean SSC time series for Platforms 1, 2 and 3 over a 7-day period. Figure B-18 shows OBS data over the same period for Platforms 4, 5 and 6. Collection of OBS data at Platforms 4, 5 and 6 was particularly difficult at low water due to the shallow depths of upstream portions of Steinberger and Corkscrew Sloughs.

Simulated and measured SSCs over a 3-day period as well as the simulated WSE at each of the platforms are plotted in Figures B-19 through B-24 for the single-layer model calibration. The ambient values of SSC match well, but differences between the simulated and measured peak values are evident. However, rough estimate of the amount of net sedimentation over lower Redwood Creek was close to the typical yearly deposition rates based on recorded dredge volumes.

An attempt to recalibrate the CST model with the multi-layer module did not provide a better fit within the time available, and further refinement of the sedimentation model was not pursued for two reasons. Firstly, other methods were available for analysis of the restoration alternatives. Secondly, and more importantly, refinement of the CST model is not expected to change the restoration plan since design modifications implemented to meet constraints at Pete's Harbor and maintain existing tidal prism through Redwood Creek (a surrogate indicator of sedimentation in lower Redwood Creek) already maximize the sediment delivery to the Middle and Outer Bair.

4. RESTORATION MODELING

4.1 APPROACH

4.1.1 Evaluation of the November 2000 Recommended Alternative

The initial version of the restoration design, developed in November 2000, consisted of filling Inner Bair with dredged material and breaching each island at several historic channel locations. It was similar to the recommended alternative (described in Section 5 of the main report) but without flow control structures in Smith and Corkscrew Sloughs. Modeling was used to assess the performance of the November 2000 alternative and the following design issues were identified:

- Potential to increase sedimentation in the Redwood Creek Shipping channel,
- Potential to increase tidal velocities in Pete's Outer Harbor, and
- Potential for low sediment supply to the restoration site, particularly Middle Bair.

4.1.2 Evaluation of the Design Modifications

The November 2000 alternative was refined through a series of model runs which simulated various changes to the restoration plan. In order to make this optimization process tractable, key independent and dependent variables were identified at the beginning of the modeling exercise. Permutations to the restoration plan were constructed by adjusting the following independent variables in the model set-up:

- Number of breaches,
- Phasing of breaches,
- Channel enlargement at Pete's Outer Harbor,
- By-pass channel around Pete's Outer Harbor,
- Dredging of Steinberger Slough, and
- Use of flow control structures in the sloughs.

The effectiveness of each design modification was assessed by examining key dependent parameters. These dependent parameters were selected based upon the design issues listed above and consisted of the following:

- Average tidal prism at Redwood Creek and Steinberger Slough,
- Peak velocity at Pete's Outer Harbor,
- Low tide drainage in Steinberger Slough,
- Net transport of suspended sediment through the sloughs, and
- Sediment accumulation in the restored islands.

The run catalogue (Table B-1) identifies the potential design solutions/modifications tested in each simulation. These potential design solutions tested in the model are described below.

4.1.2.1 Sedimentation in the Redwood Creek Shipping Channel

The potential for increased sedimentation in Redwood Creek for the November 2000 alternative is due to the fact that the restored tidal flows to and from Middle and Inner Bair Islands draw largely from the shipping channel rather than Steinberger Slough. As the Redwood Creek shipping channel is dredged and vastly oversized in relation to its tidal flow, it serves as an effective sediment trap. The sediment transport modeling suggests that the November 2000 alternative would result in an approximate three-fold increase in the rate of sedimentation within the shipping channel (see results in Section 4.2) due to an increase in the flow of sediment-laden water through Redwood Creek.

Initial sediment transport simulations indicated that increases in flow through Redwood Creek resulted in increased shoaling along the shipping channel. Therefore, the design criteria used in the development of design modifications was to match tidal prism through Redwood Creek and direct flow through Steinberger Slough. The potential design solutions developed to resolve this issue include:

- constricting flows in Smith and Corkscrew Sloughs using flow control structures,
- altering the number, size, and location of breaches to preferentially breach to Steinberger and Corkscrew Sloughs,
- dredging Steinberger Slough, and
- phasing restoration so that Outer and Middle Bair scour and deepen Steinberger Slough before breaching Inner Bair.

Section 5 of the main report provides descriptions of the proposed flow control structures.

4.1.2.2 Tidal Velocities at Pete's Outer Harbor

The above design approach and solutions were also applied to address the potential for increases in tidal velocities at Pete's Outer Harbor. Results from the modeling of the November 2000 alternative show an increase in velocities at Outer Pete's Harbor from approximately one foot per second (fps) under existing conditions to nearly three fps (see results in Section 4.3). Generally accepted marina design guidelines indicate that velocities above 1 fps pose navigation difficulties for small watercraft and post-project velocities of up to 3 fps are therefore not likely to be acceptable to the marina. Although the increase in velocities would diminish over time as the channel scours and the islands fill with sediment, there are design solutions to expedite or avoid this process. The design solutions discussed above in reference to sedimentation in the Redwood Creek shipping channel (Section 4.1.1) serve to direct increased tidal flows preferentially towards Steinberger and Corkscrew Sloughs and away from Redwood Creek and Smith Slough, thus reducing tidal flows and velocities at Pete's Outer Harbor. Additional design solutions for Pete's Outer Harbor include:

- Widening Smith Slough in the vicinity of the harbor to increase the cross-sectional flow area and
- Constructing a bypass channel through Middle Bair to route flow around Pete's Outer Harbor.

4.1.2.3 Sediment Supply to the Restoration Site

The phenomena of increased sedimentation rates in the Redwood Creek shipping channel for the November 2000 alternative has the added ramification of potentially decreasing sediment supply to the restoration site, particularly Middle and Inner Bair Islands. The primary sediment sources for natural estuarine deposition at Inner, Middle, and Outer Bair Islands are the shallow mudflats of San Francisco Bay. When sediment derived from this source is conveyed to the restoration site through Redwood Creek, sediment that would otherwise be available for deposition within the restoration site settles out in the oversized shipping channel. Restored areas that draw flow and sediments largely from Redwood Creek, such as Middle and Inner Bair Islands in the November 2000 alternative, will have a lower sediment supply than areas that draw directly from the Bay or Steinberger Slough. Decreased sediment supply will delay site evolution and vegetation. This is more of an issue for Middle Bair than Inner Bair, since Middle Bair relies on estuarine sedimentation rather than dredge material for habitat evolution. By directing tidal flows away from Redwood Creek and towards Steinberger Slough, the same design solutions employed to resolve the Redwood Creek shipping channel siltation issue have the effect of resolving the sediment supply issue as well.

4.1.3 August 2002 Recommended Alternative

After testing the various design solutions in a series of model runs listed in Table B-1, we arrived at a new recommended alternative. The design solution for the recommended alternative, referred to here as the August 2002 Recommended Alternative, is to include flow control structures in Smith and Corkscrew Sloughs and to eliminate one Middle Bair breach such that tidal exchange to this island is provided only from the Steinberger Slough side of the flow control structures.

4.2 RESULTS

Model results for key performance indicators are listed by model run in Tables B-1 and B-2 for hydrodynamics and sediment transport, respectively. This section compares model results for existing conditions and both the November 2000 and August 2002 alternatives for the following performance parameters:

- Sedimentation in the Redwood Creek shipping channel,
- Velocities at Pete's Outer Harbor, and
- Sediment supply to the restored islands.

Overall, the refined design presented here (August 2002 Alternative) has successfully resolved potential problems with the previous November 2000 Alternative.

4.2.1 Sedimentation in the Redwood Creek Shipping Channel

Sediment transport modeling indicates that the November 2000 alternative would result in approximately three times the existing rates of siltation rates in the shipping channel (Table B-2). Since initial sediment transport simulations (Runs 1-7) indicated that an increase in tidal prism results in increased siltation rates, the design criteria was to match restored tidal prism with existing tidal prism in the shipping channel. In the later runs (Runs 8-15), tidal prism through Redwood Creek was used as an indicator for potential sediment accumulation in the channel. Using a hydrodynamic design criterion (tidal prism) rather than a sediment transport criterion (siltation rates) allowed us to model and analyze each run more quickly and therefore to increase the total number of scenarios modeled within the scope of the study. Tidal prism at the mouth of Steinberger Slough is shown on Table B-2 and was used as a preliminary measure of project performance. For the August 2002 Alternative (Run 15X), we also conducted a more detailed comparison of tidal prisms at several Redwood Creek cross-section locations.

For the August 2002 Alternative, model results show that tidal prism in Redwood Creek shipping channel is about 15% less than under existing conditions. Sedimentation rates in the shipping channel are therefore expected to remain unchanged or decrease slightly. This is supported by the sediment transport modeling results for Runs 5 and 6, which are similar in configuration to the August 2002 alternative. These results show no increase in sediment accumulation in Redwood Creek.

4.2.2 Velocities at Pete's Outer Harbor

Peak tidal velocities at Pete's Outer Harbor of approximately 1.2 to 1.3 m/s were modeled for the November 2000 Alternative, which are over three times greater than existing peak velocities as shown in Figure B-24. For the August 2002 Alternative, model results indicate that the tidal prism passing through Redwood does not increase, therefore peak velocities are about the same as existing conditions.

4.2.3 Sediment Supply to the Restored Islands

The hydrodynamic modeling results for the August 2002 Alternative indicate that most of the water supplied to the restored islands will be conveyed through Steinberger Slough, avoiding the losses of sediment to the Redwood Creek sediment "sink." Although sediment transport modeling was not conducted for the August 2002 alternative (hydrodynamic modeling only), results for Runs 5 and 6, which are similar in configuration to the August 2002 alternative, are available. These results indicate initial sedimentation rates of approximately 15 mm/yr for Outer Bair, 5 to 9 mm/yr for Middle Bair, and 0 to 1 mm/yr for Inner Bair.

4.2.4 Other Considerations

Hydrodynamic simulations of the August 2002 Alternative indicate elevated low water levels at the upstream reaches of Steinberger Slough. Figure B-25 plots water level time series from the confluence of Steinberger and Smith Sloughs for existing conditions as well as restored conditions.

The impacts of elevated low waters on flooding is being examined in a separate task, and results from that analysis will be forthcoming in a technical memorandum. However, these effects are expected to be temporary until sufficient scouring occurs along Steinberger Slough and within the channels in the interior of the islands.

REFERENCES

Danish Hydraulic Institute (DHI) 2001. MIKE 11 General Reference Manual.

Schoellhamer, David H. 2001. Singular Spectrum Analysis for Time Series with Missing Data, Geophysical Research Letters.

ATTACHMENTS

BAIR ISLAND RESTORATION

TABLE B-1. Summary of Modeling Runs and Hydrodynamic Results

RUN ID	Description	Time	Site Evolution Simulated	DESIGN MODIFICATION INCLUDED IN RUN						HYDRODYNAMIC RESULTS			
				# breaches	phasing	Channel Enlargement at Pete's Outer Harbor	Pete's Harbor Bypass Channel	Dredge Steinberger	Locations of flow control structures	Elevation of LLW at Smith @ Stein. Sl [m NGVD]	Peak Velocity at Pete's Outer Harbor [m/s]	Tidal Prism [M m^3]	
												Redwood Creek	Steinberger Slough
1	Existing Conditions	t (0)	none	none	n.a.	none	none	none	none	-1.62	0.38	5.8	1.1
3	November 2000 Recommended Alternative, initial conditions	t (0)	none	12	simultaneous	none	none	none	none	-1.54	1.28	8.0	2.1
4	November 2000 Recommended Alternative, long-term conditions	t (X)	long-term slough scour	12	simultaneous	none	none	none	none	-1.54	1.20	7.9	2.3
5	Restoration with channel blocks and one MB breach to east of Corkscrew block	t (0)	none	12	simultaneous	none	none	none	Smith Sl. (east of MB3) and Corkscrew Sl. (between OB2 and MB2)	0.28	0.04	4.9	2.7
6	Restoration with channel blocks	t (0)	none	12	simultaneous	none	none	none	Smith Sl. (east of MB3) and Corkscrew Sl. (east of MB2)	0.35	0.05	4.6	2.5
7	Phased breaching of Middle Bair	t (MB)	marshplain sedimentation at Inner and Outer Bair	12	MB breached after OB and IB reach pickleweed elevation	none	none	none	none	-1.56	1.08	7.4	1.6
8	Widening Smith Sl. At Pete's Harbor	t (0)	none	12	simultaneous	yes, small	none	none	none	-1.55	0.79	7.6	2.1
9	Restoration with channel block at Inner Bair and Wide/Deep of Smith Sl.	t (0)	none	12	simultaneous	yes	none	none	Smith Slough between IB1 and IB2	-0.46	0.37	6.5	2.7
10	Re-establish Meander Thru Inner Bair + Wide/Deep of Smith Sl. + block at Corkscrew Sl.	t (0)	none	12	simultaneous	yes	none	none	Smith Sl. (between IB1 & IB2) and Corkscrew Sl. (east of MB2)	0.01	0.39	5.5	2.7
11	Re-establish Meander Thru Inner Bair + Wide/Deep of Smith Sl. + block at Corkscrew Sl.	t (X)	long-term slough scour	12	simultaneous	yes	none	none	Smith Sl. (between IB1 & IB2) and Corkscrew Sl. (east of MB2)	-0.16	0.4	5.5	3.1
12a	Only breach MB to Corkscrew with block in Smith Slough	t (0)	none	9	simultaneous	yes	none	none	Smith Slough between IB1 and IB2	-0.34	0.21	7.3	1.4
12b	Only breach MB to Corkscrew	t (0)	none	9	simultaneous	none	none	none	none	-1.48	0.48	7.1	1.6
13a	Dredge Steinberger	t(0)	none	12	simultaneous	none	none	mouth to upstream of Corkscrew	none	-1.30	1.15	7.8	2.5
13b	Dredge Steinberger with channel blocks	t(0)	none	12	simultaneous	none	none	mouth to upstream of Corkscrew	Smith Sl. (between IB1 & IB2) and Corkscrew Sl. (east of MB2)	-1.00	0.69	6.7	4.0
13c	Long Dredge of Steinberger with channel blocks	t(0)	none	12	simultaneous	none	none	mouth to Smith	Smith Sl. (between IB1 & IB2) and Corkscrew Sl. (east of MB2)	-1.02	0.68	5.5	4.3
14a	By-Pass Pete's Harbor with blocks	t(0)	none	12	simultaneous	yes	bypass channel	none	Smith Sl. (between IB1 & IB2) and Corkscrew Sl. (east of MB2)	0.05	0.49	9.0	2.7
14b	By-Pass Pete's Harbor without blocks	t(0)	none	12	simultaneous	none	bypass channel	none	none	-1.63	0.57	8.6	2.1
15a	August 2002 Recommended Alternative, initial conditions	t(0)	none	11	simultaneous	none	none	none	Smith Sl. (between IB1 & IB2) and Corkscrew Sl. (east of MB2)	0.24	0.42	5.0	2.6
15b	August 2002 Recommended Alternative, with dredging	t(x)	none	11	simultaneous	none	none	mouth to Smith	Smith Sl. (between IB1 & IB2) and Corkscrew Sl. (east of MB2)	-1.06	0.39	5.0	4.3
15x	August 2002 Recommended Alternative, long-term conditions	t(x)	long-term slough scour	11	simultaneous	none	none	none	Smith Sl. (between IB1 & IB2) and Corkscrew Sl. (east of MB2)	0.06	0.42	5.0	3.6

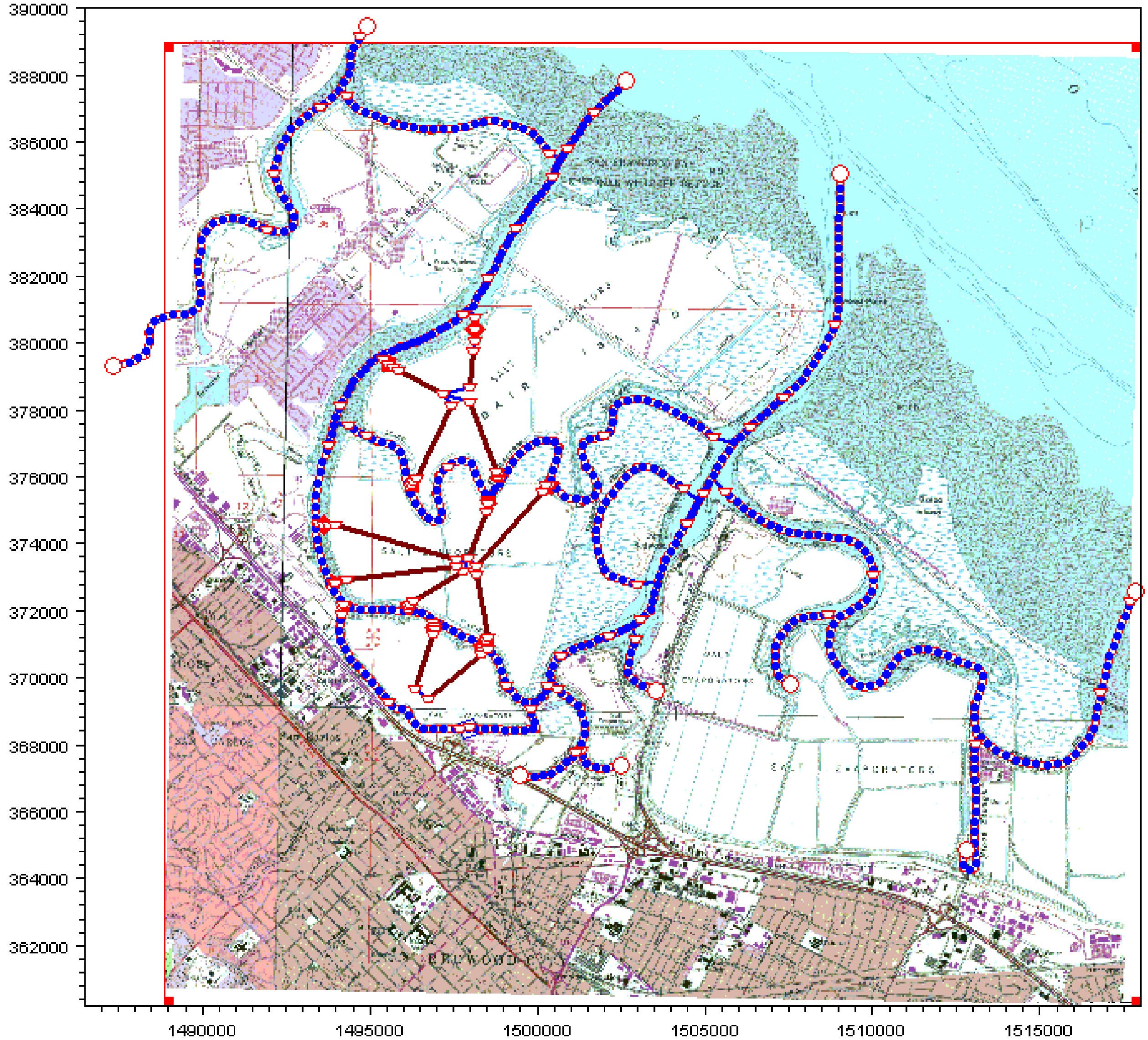
Note: Tidal prism determined by computed cumulative discharge from 6/17/2001 22:00 to 6/18/2001 23:00
LLW = lower low water, taken as LLW SMITH @ STEINBERGER on 6/23
For Runs 3-14, MB3 breach is east of IB2; for Run 15, there are no Middle Bair breaches east of IB2 and MB3 is west of IB1.
IB = Inner Bair; MB = Middle Bair; OB = Outer Bair

BAIR ISLAND RESTORATION

TABLE B-2. Summary of Modeling Runs and Sediment Transport Results

RUN ID	Description	Time	SEDIMENT TRANSPORT RESULTS: Sedimentation Rates (mm/yr)			Tidal Prism [M m^3] (for reference)		Sediment Transport [M kg/yr]			Sediment Accumulation in Lower Redwood Creek [M kg/yr]
			Outer Bair	Middle Bair	Inner Bair	Redwood Creek	Steinberger Slough	Smith @ RC	Stein @ Bay	Cork @ RC	Project
1	Existing Conditions	t (0)	n.a.	n.a.	n.a.	5.8	1.1	6.2	5.0	2.8	33
3	November 2000 Recommended Alternative, initial conditions	t (0)	28	12	5	8.0	2.1	18.1	33.4	9.0	106
4	November 2000 Recommended Alternative, long-term conditions	t (X)	25	13	7	7.9	2.3	19.2	32.4	11.7	96
5	Restoration with channel blocks and one MB breach to east of Corkscrew block	t (0)	15	9	0	4.9	2.7	0.3	43.5	13.2	31
6	Restoration with channel blocks	t (0)	15	5	1	4.6	2.5	0.4	52.5	1.7	30
7	Phased breaching of Middle Bair	t (MB)	7	10	1	7.4	1.6	14.6	17.1	9.7	97
8	Widening Smith Sl. At Pete's Harbor	t (0)	n.a.	n.a.	n.a.	7.6	2.1	n.a.	n.a.	n.a.	n.a.
9	Restoration with channel block at Inner Bair and Wide/Deep of Smith Slough	t (0)	n.a.	n.a.	n.a.	6.5	2.7	n.a.	n.a.	n.a.	n.a.
10	Re-establish Meander Thru Inner Bair + Wide/Deep of Smith Sl. + block at Corkscrew Sl.	t (0)	n.a.	n.a.	n.a.	5.5	2.7	n.a.	n.a.	n.a.	n.a.
11	Re-establish Meander Thru Inner Bair + Wide/Deep of Smith Sl. + block at Corkscrew Sl.	t (X)	n.a.	n.a.	n.a.	5.5	3.1	n.a.	n.a.	n.a.	n.a.
12a	Only breach MB to Corkscrew with block in Smith Slough	t (0)	n.a.	n.a.	n.a.	7.3	1.4	n.a.	n.a.	n.a.	n.a.
12b	Only breach MB to Corkscrew	t (0)	n.a.	n.a.	n.a.	7.1	1.6	n.a.	n.a.	n.a.	n.a.
13a	Dredge Steinberger	t(0)	n.a.	n.a.	n.a.	7.8	2.5	n.a.	n.a.	n.a.	n.a.
13b	Dredge Steinberger with channel blocks	t(0)	n.a.	n.a.	n.a.	6.7	4.0	n.a.	n.a.	n.a.	n.a.
13c	Long Dredge of Steinberger with channel blocks	t(0)	n.a.	n.a.	n.a.	5.5	4.3	n.a.	n.a.	n.a.	n.a.
14a	By-Pass Pete's Harbor with blocks	t(0)	n.a.	n.a.	n.a.	9.0	2.7	n.a.	n.a.	n.a.	n.a.
14b	By-Pass Pete's Harbor without blocks	t(0)	n.a.	n.a.	n.a.	8.6	2.1	n.a.	n.a.	n.a.	n.a.
15a	August 2002 Recommended Alternative	t(0)	n.a.	n.a.	n.a.	5.0	2.6	n.a.	n.a.	n.a.	n.a.
15b	August 2002 Recommended Alternative	t(x)	n.a.	n.a.	n.a.	5.0	4.3	n.a.	n.a.	n.a.	n.a.
15x	August 2002 Recommended Alternative	t(x)	n.a.	n.a.	n.a.	5.0	3.6	n.a.	n.a.	n.a.	n.a.

Note: Tidal prism determined by computed cumulative discharge from 6/17/2001 22:00 to 6/18/2001 23:00
LLW = lower low water, taken as LLW SMITH @ STEINBERGER on 6/23
For Runs 3-14, MB3 breach is east of IB2; for Run 15, there are no Middle Bair breaches east of IB2 and MB3 is west of IB1.
IB = Inner Bair; MB = Middle Bair; OB = Outer Bair



NOTES: Planview of network of 1D channels used in numerical model. Tidal sloughs are constructed directly from surveyed bathymetery. Restored interiors of Outer, Middle and Inner Bair Islands are idealized by prismatic channels and are based to topographic surveys, draignage areas, and breach configuration.

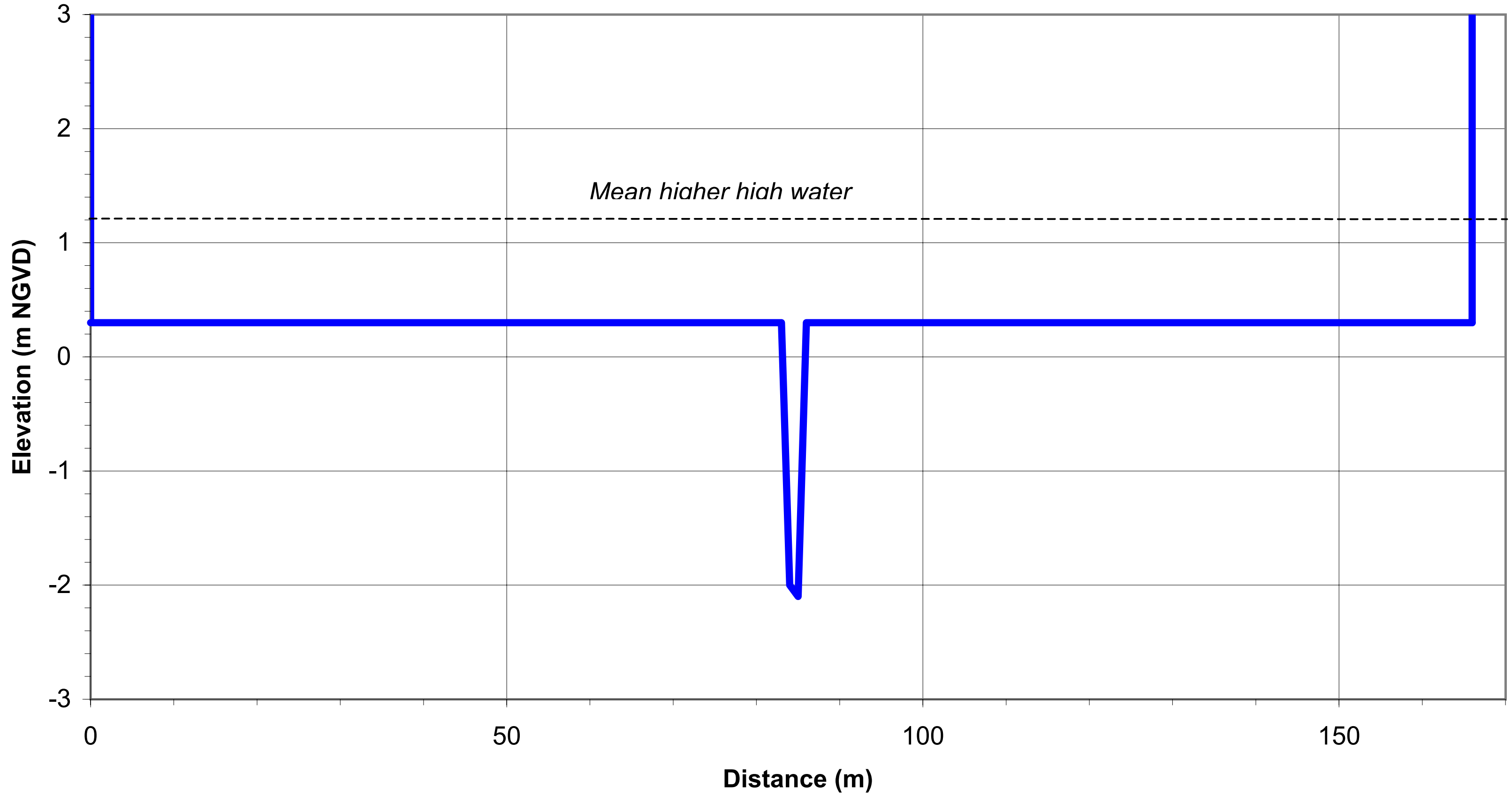
Figure B-1

Bair Island Restoration

MIKE11 Model Layout

PWA

PWA #: 1413.01



NOTES: Pond elevation is based on average elevation, with length and width selected to match drainage area.

figure B-2

Bair Island Restoration

Example of Pond Interior Prismatic Channel Cross-Section

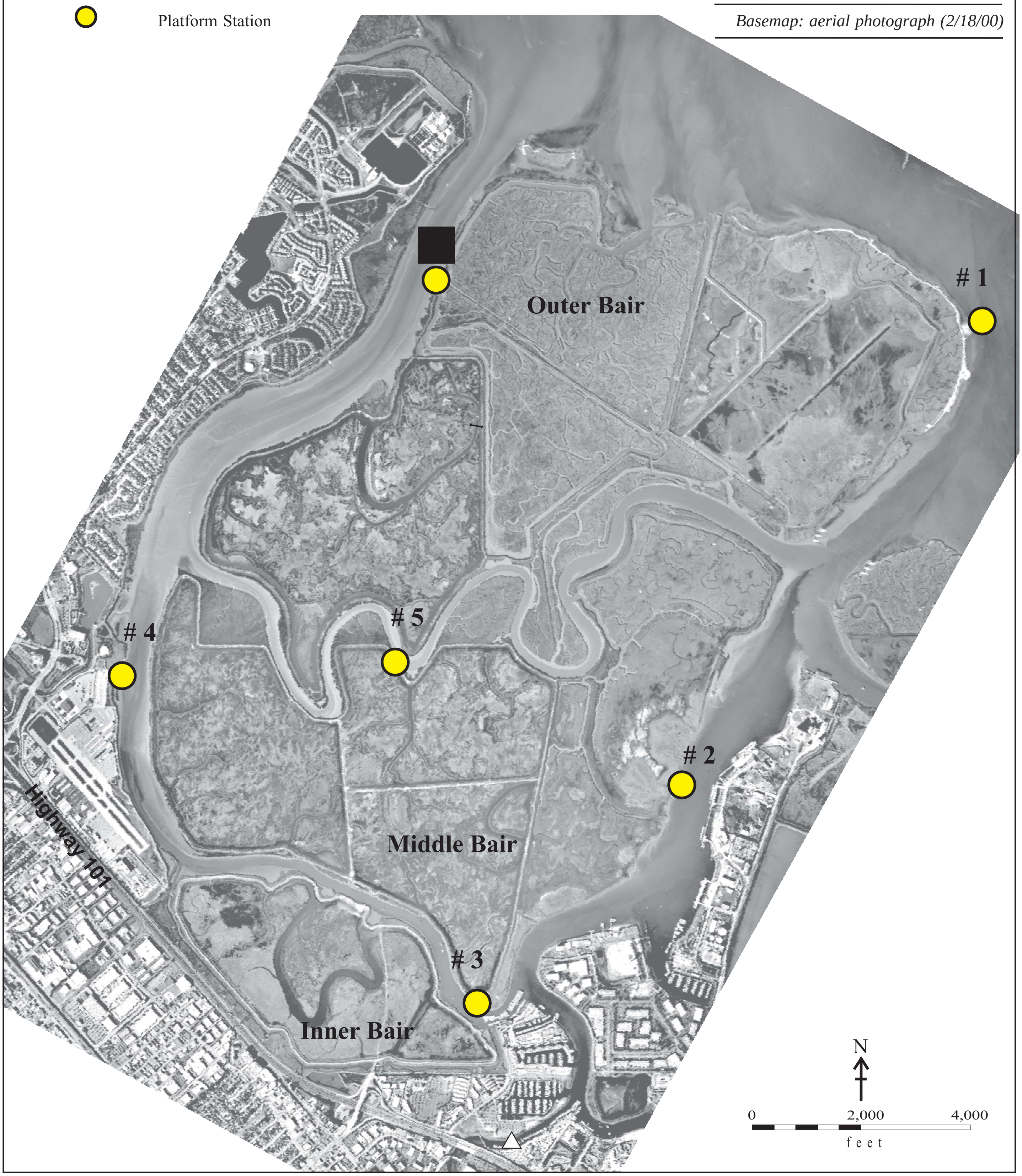
PWA

PWA #:1413

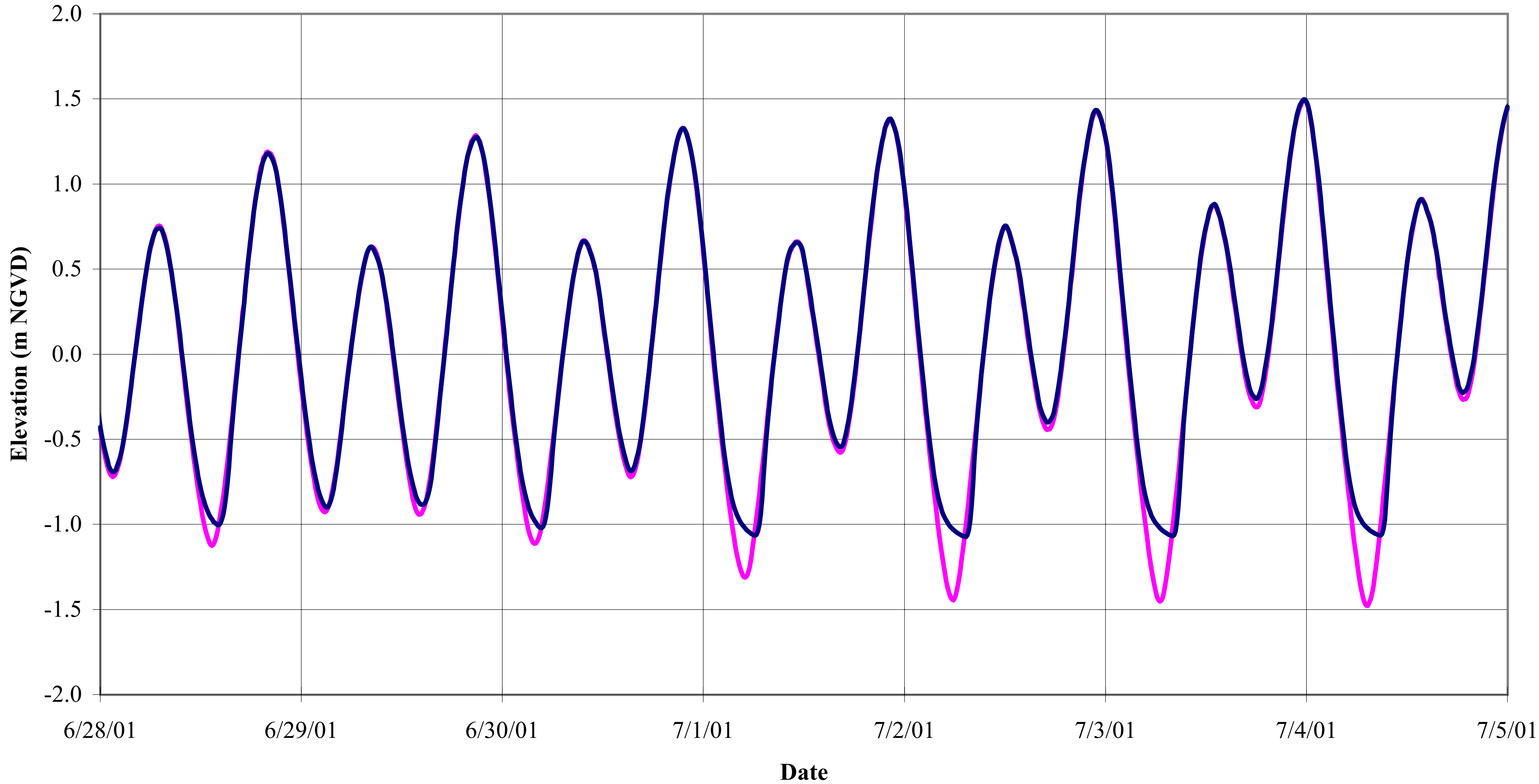
Figure B-3

Field Survey Locations

Basemap: aerial photograph (2/18/00)



PWA



Source: PWA flield survey (vented pressure transducer)

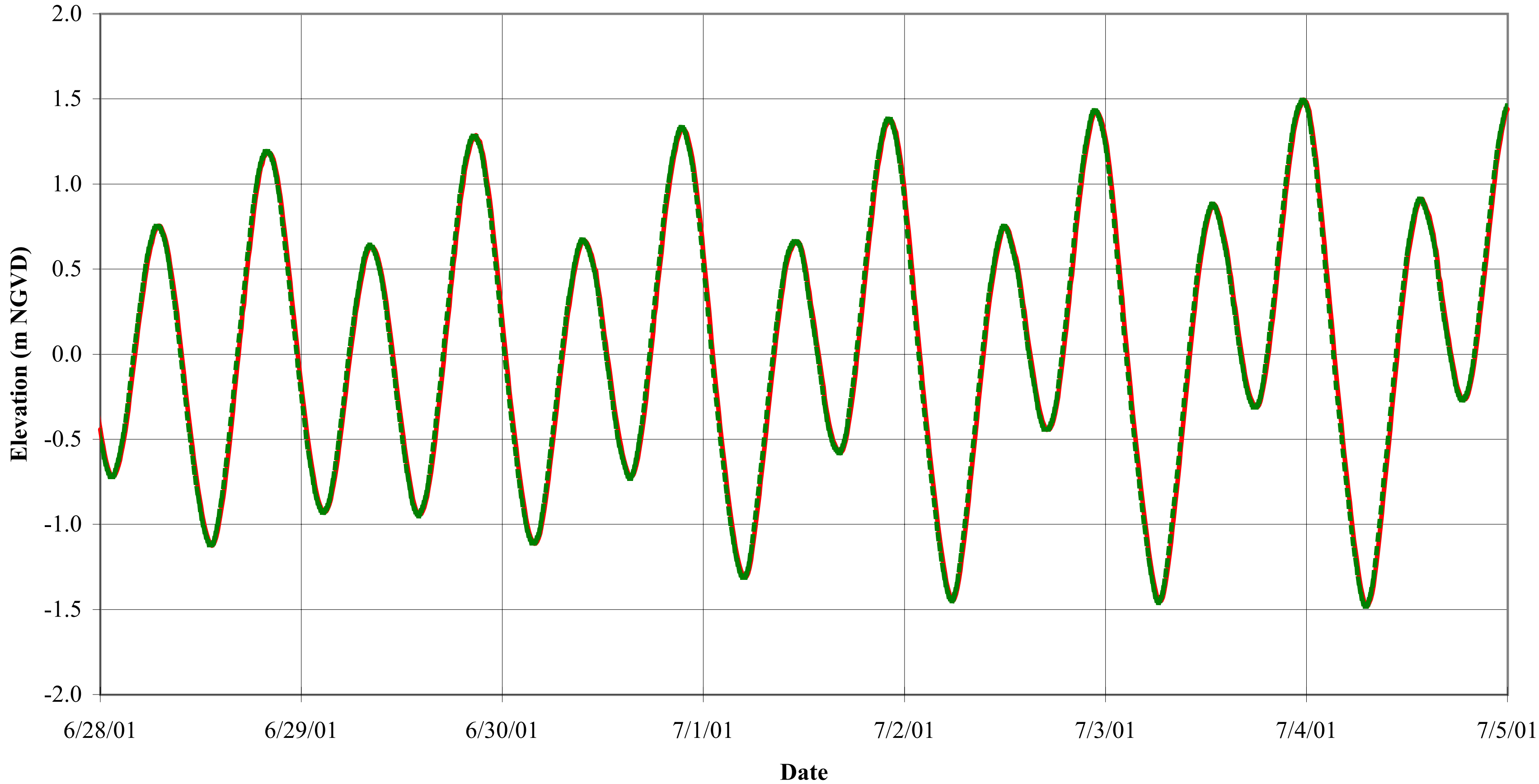
Figure B-4

Bair Island Restoration

Water Surface Eleivations (Boundary Conditions)

PWA

PWA #: 1413.01



Source: PWA flield survey (vented pressure transducer) and numerical simulation

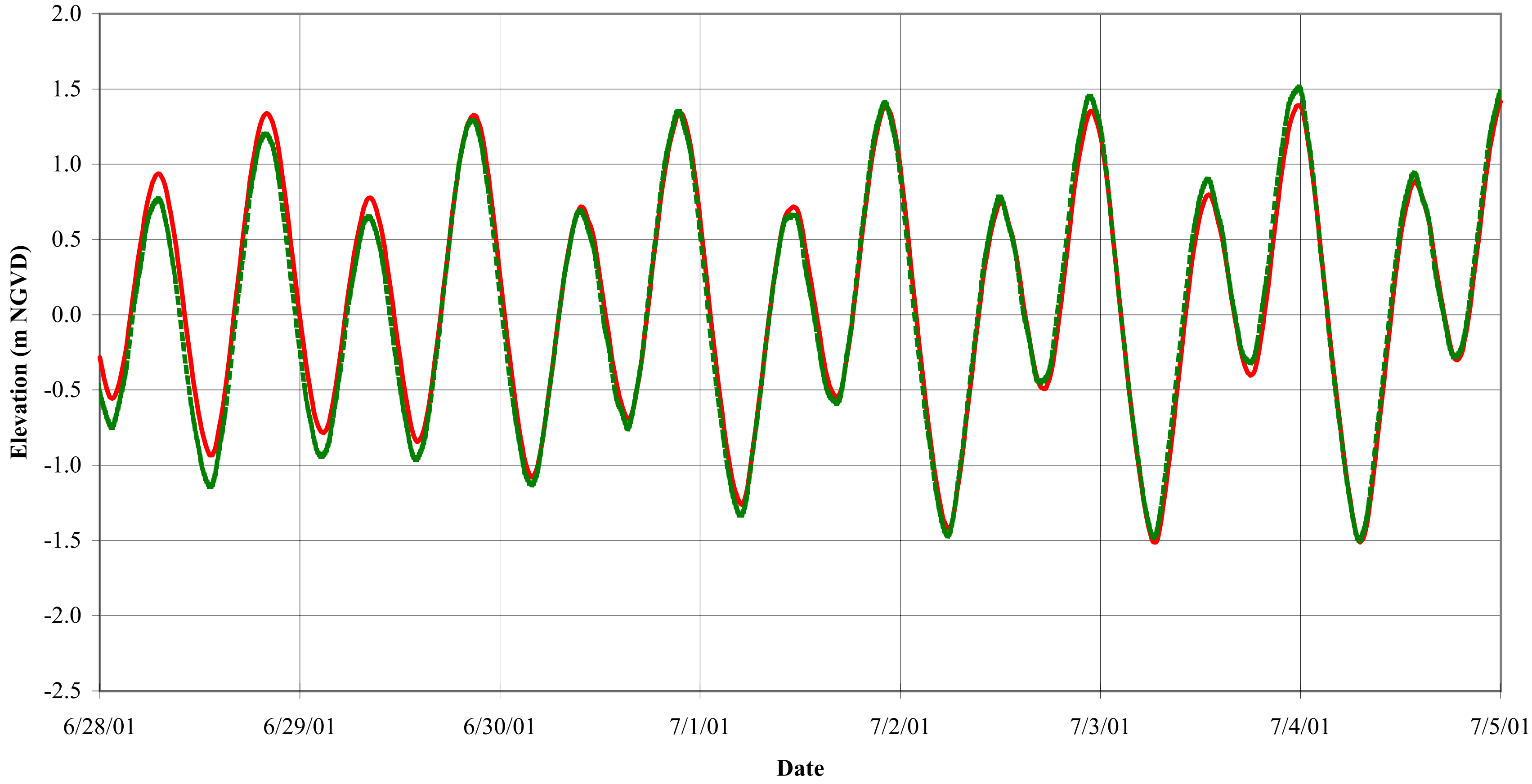
Figure B-5

Bair Island Restoration

Water Surface Elevations Platform 1

PWA

PWA #: 1413.01



Source: PWA flield survey (unvented pressure transducer) and numerical simulation

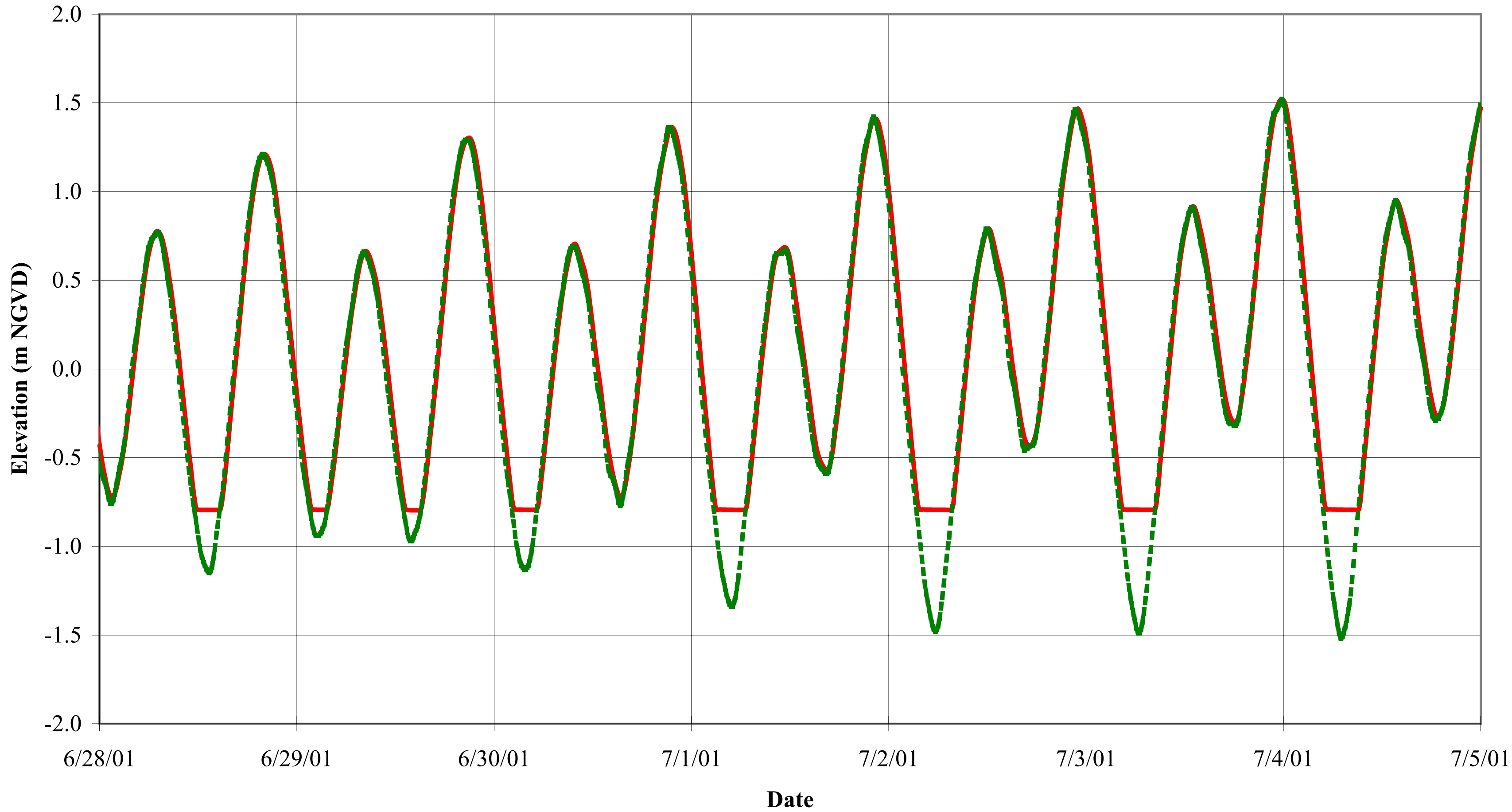
Figure B-6

Bair Island Restoration

Water Surface Elevations Platform 2

PWA

PWA #: 1413.01



Source: PWA flield survey (vented pressure transducer) and numerical simulation

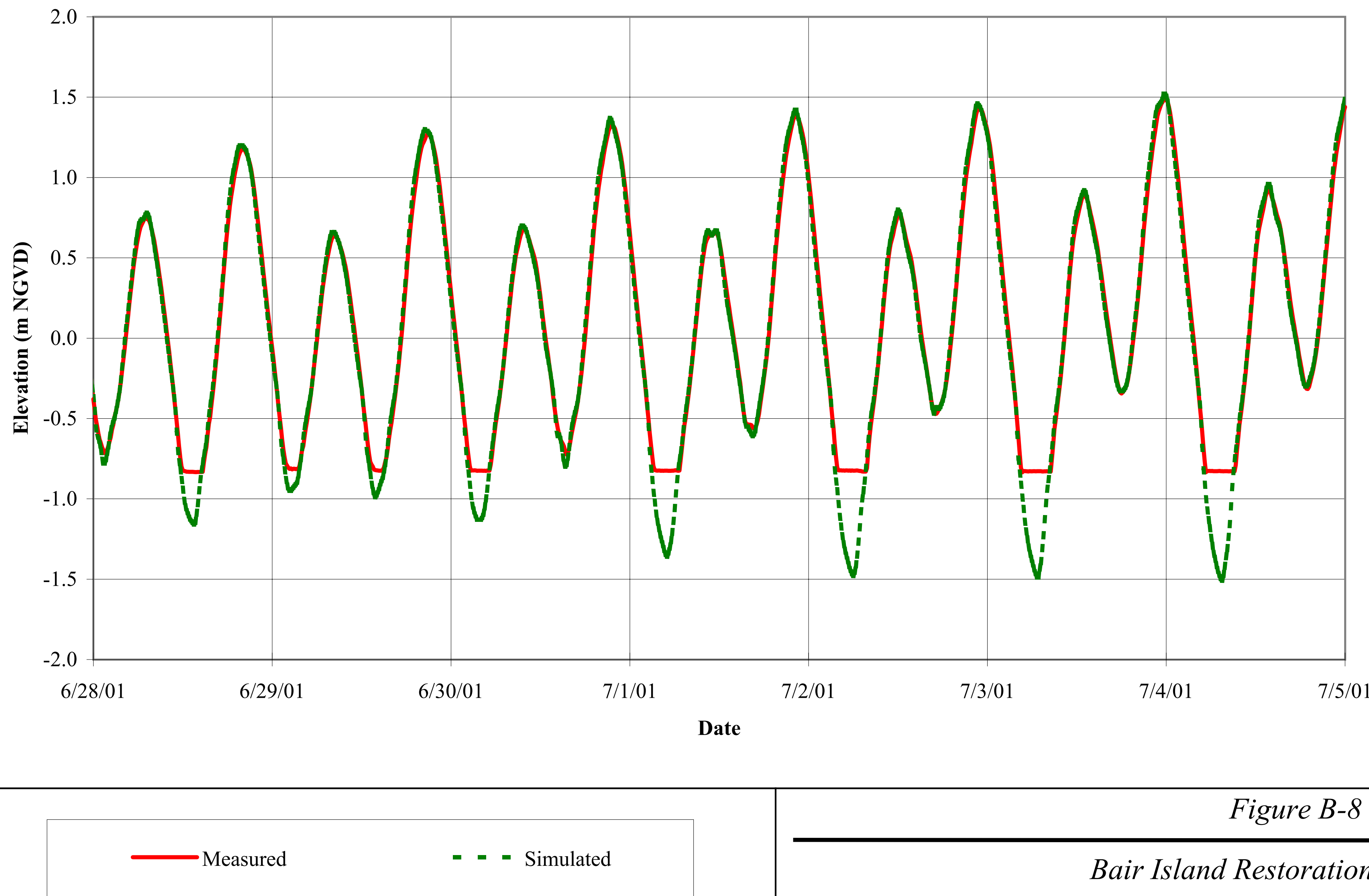
Figure B-7

Bair Island Restoration

Water Surface Elevations Platform 3

PWA

PWA #: 1413.01



Source: PWA flield survey (vented pressure transducer) and numerical simulation

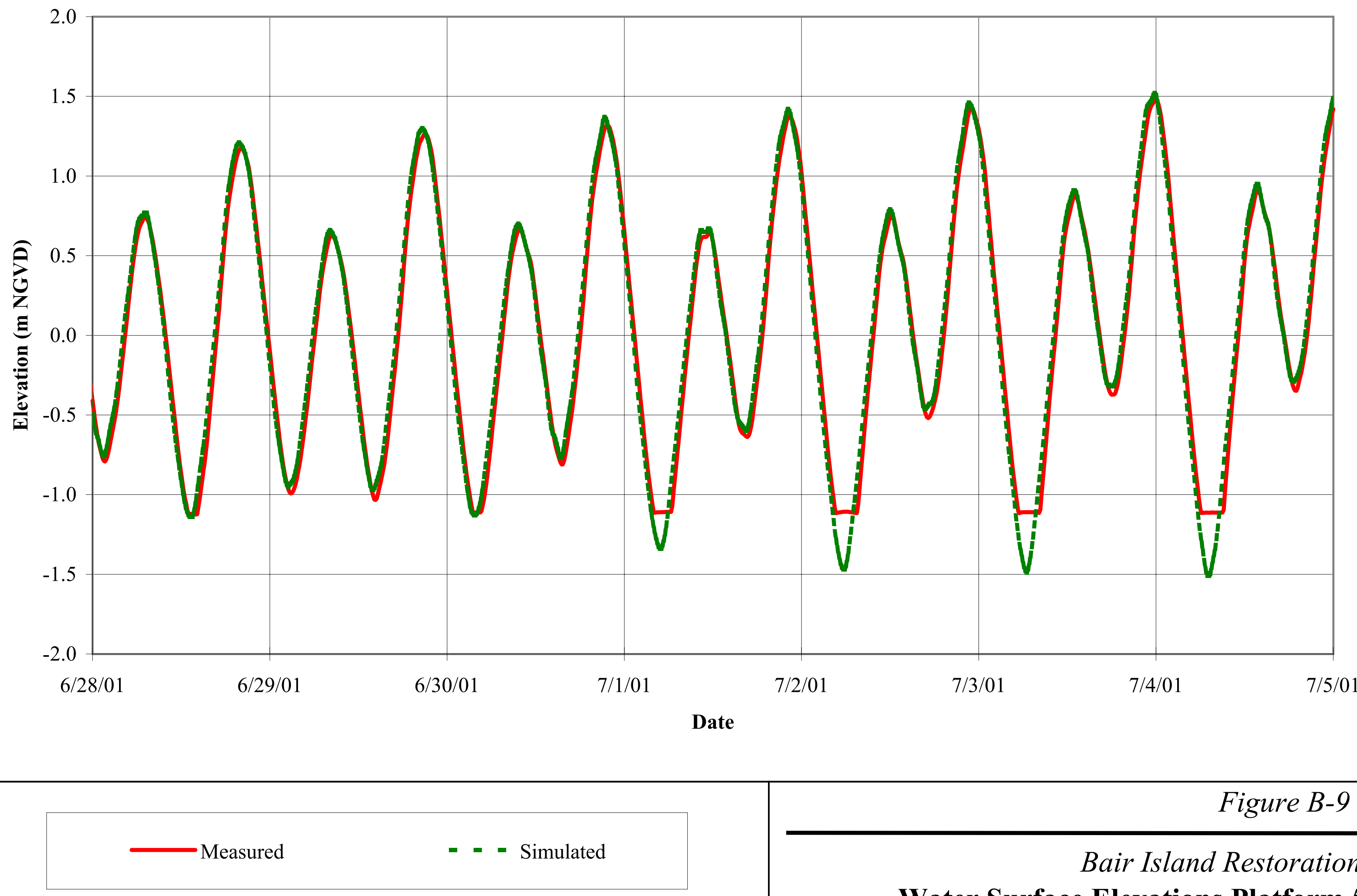
Figure B-8

Bair Island Restoration

Water Surface Elevations Platform 4

PWA

PWA #: 1413.01



Source: PWA flield survey (vented pressure transducer) and numerical simulation

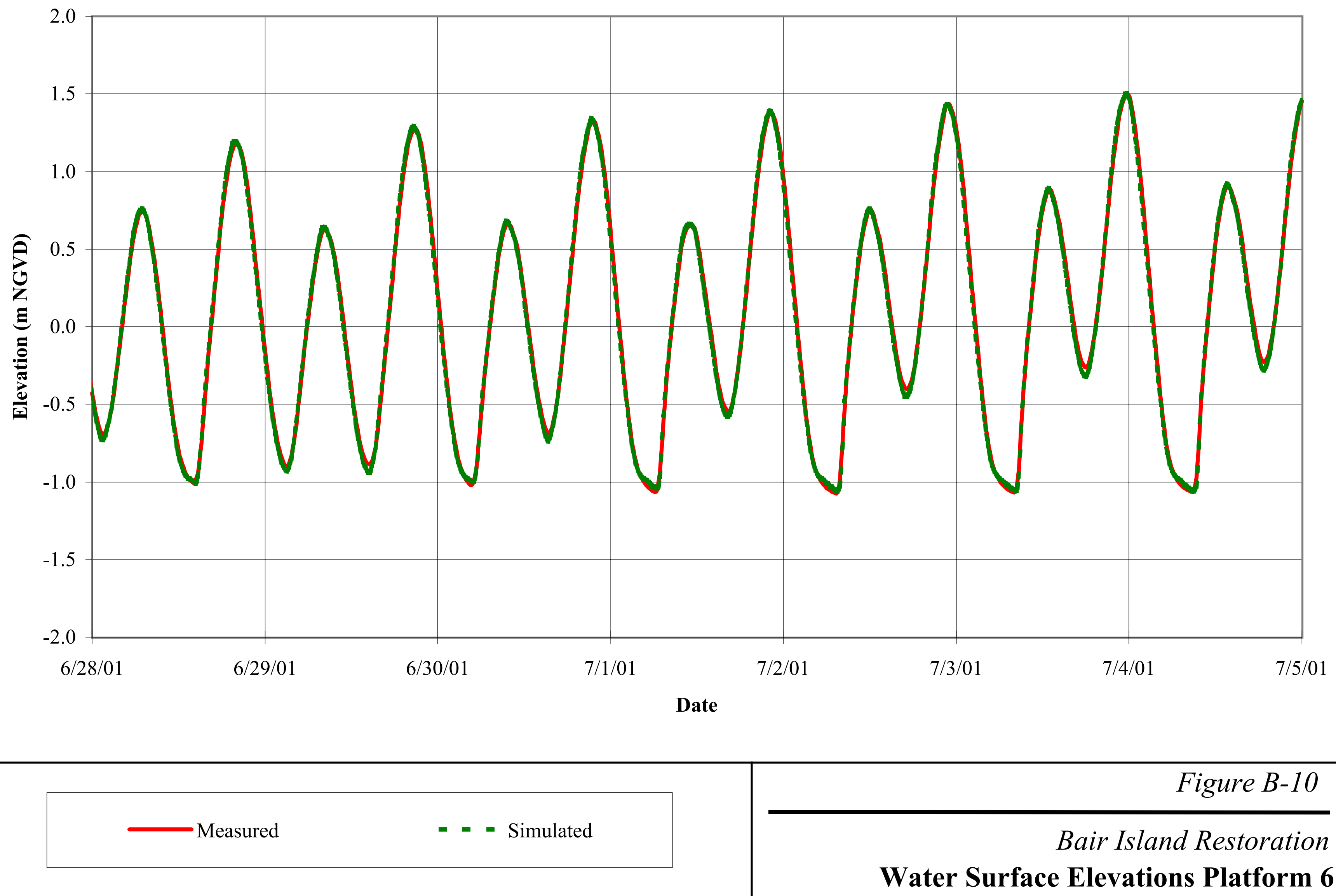
Figure B-9

Bair Island Restoration

Water Surface Elevations Platform 5

PWA

PWA #: 1413.01



Source: PWA flield survey (vented pressure transducer) and numerical simulation

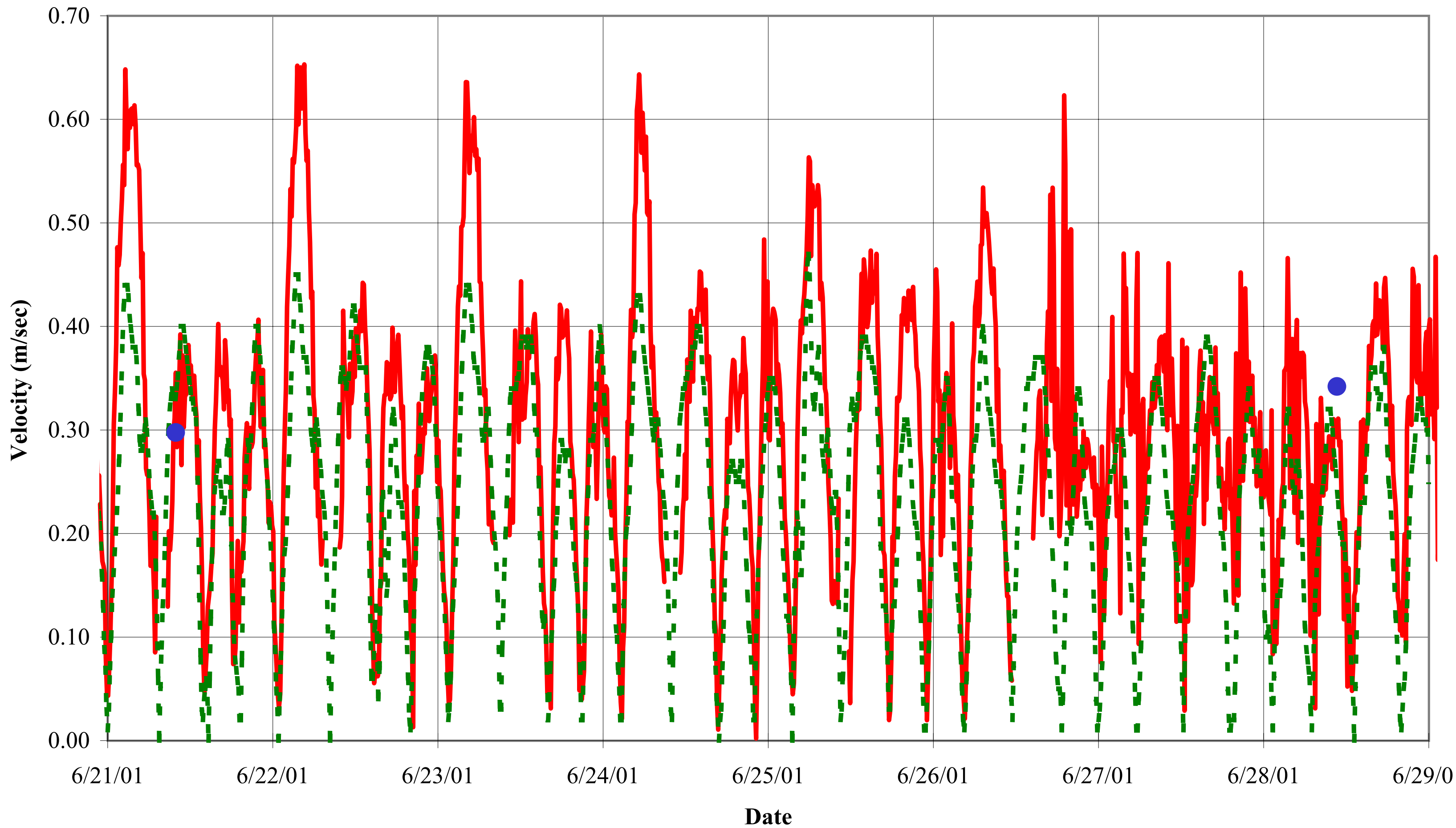
Figure B-10

Bair Island Restoration

Water Surface Elevations Platform 6

PWA

PWA #: 1413.01



Source: PWA field survey (pt vel measurements) and numerical simulation

Figure B-11

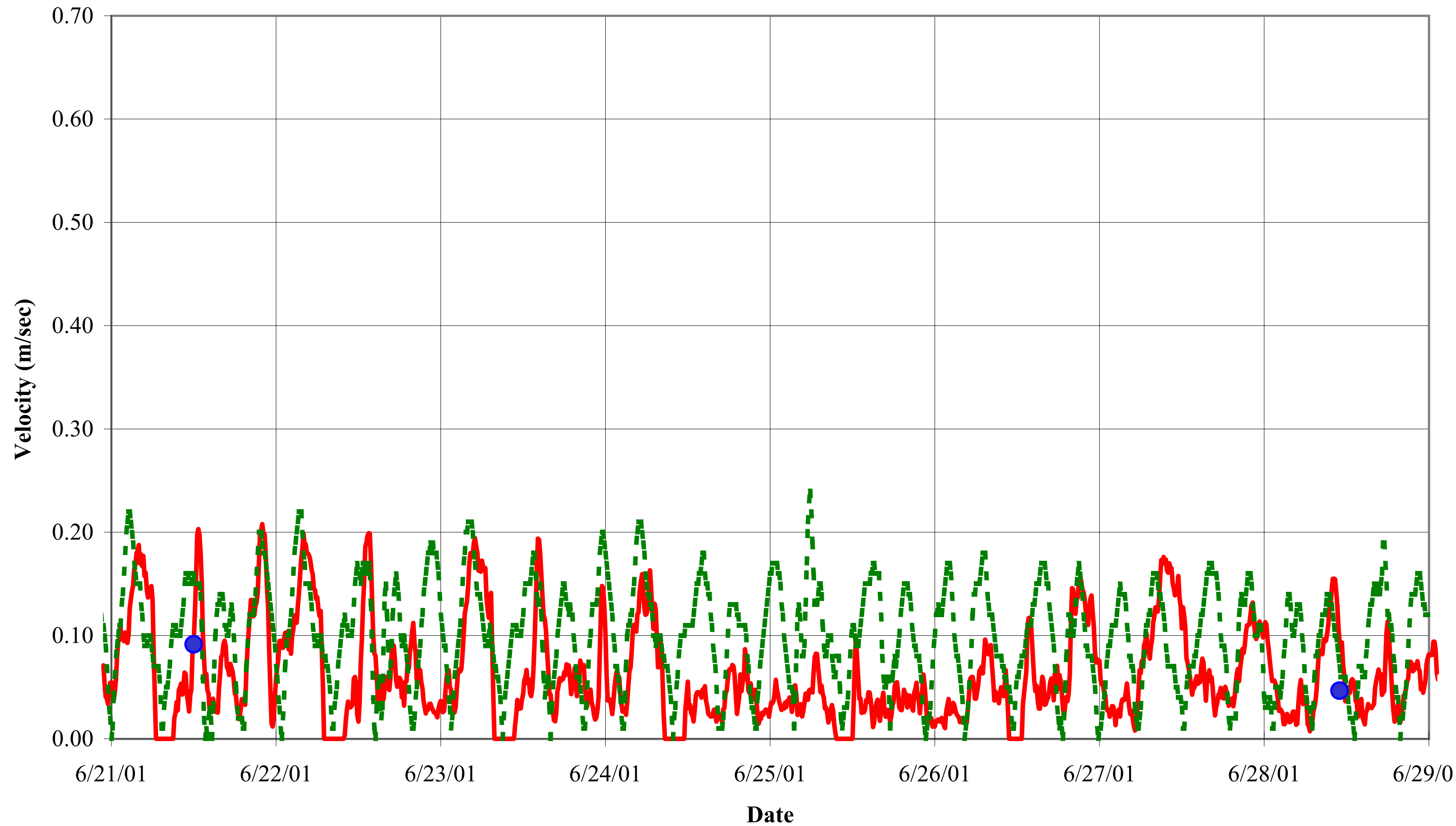
Bair Island Restoration

Measured vs. Simulated Current Velocity

Platform 1

PWA

PWA #: 1413.01



Point Data | Simulated | ADCP Data

Source: PWA field survey (pt vel measurements) and numerical simulation

Figure B-12

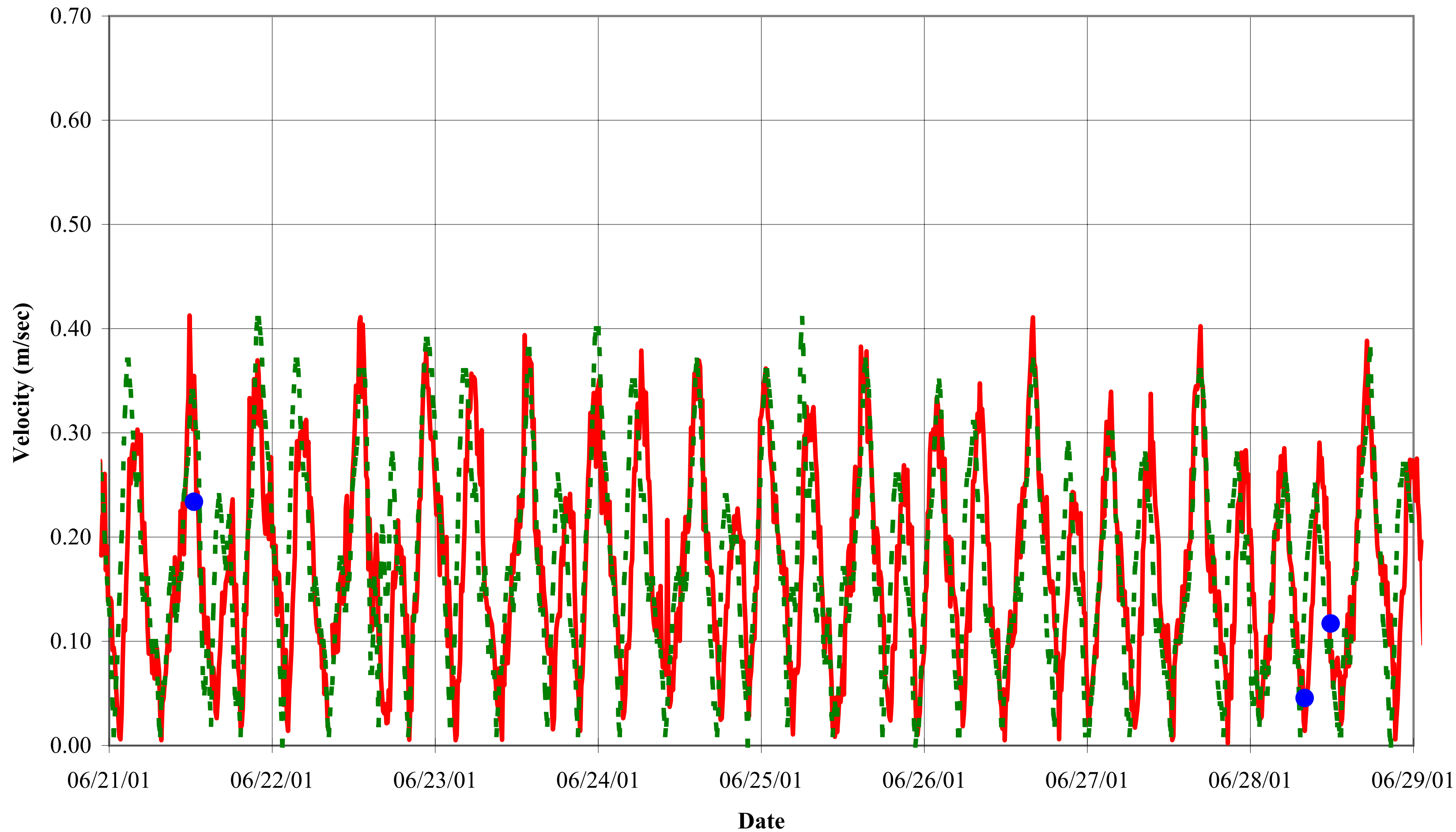
Bair Island Restoration

Measured vs. Simulated Current Velocity

Platform 2

PWA

PWA #: 1413.01



Source: PWA field survey (pt vel measurements) and numerical simulation

Figure B-13

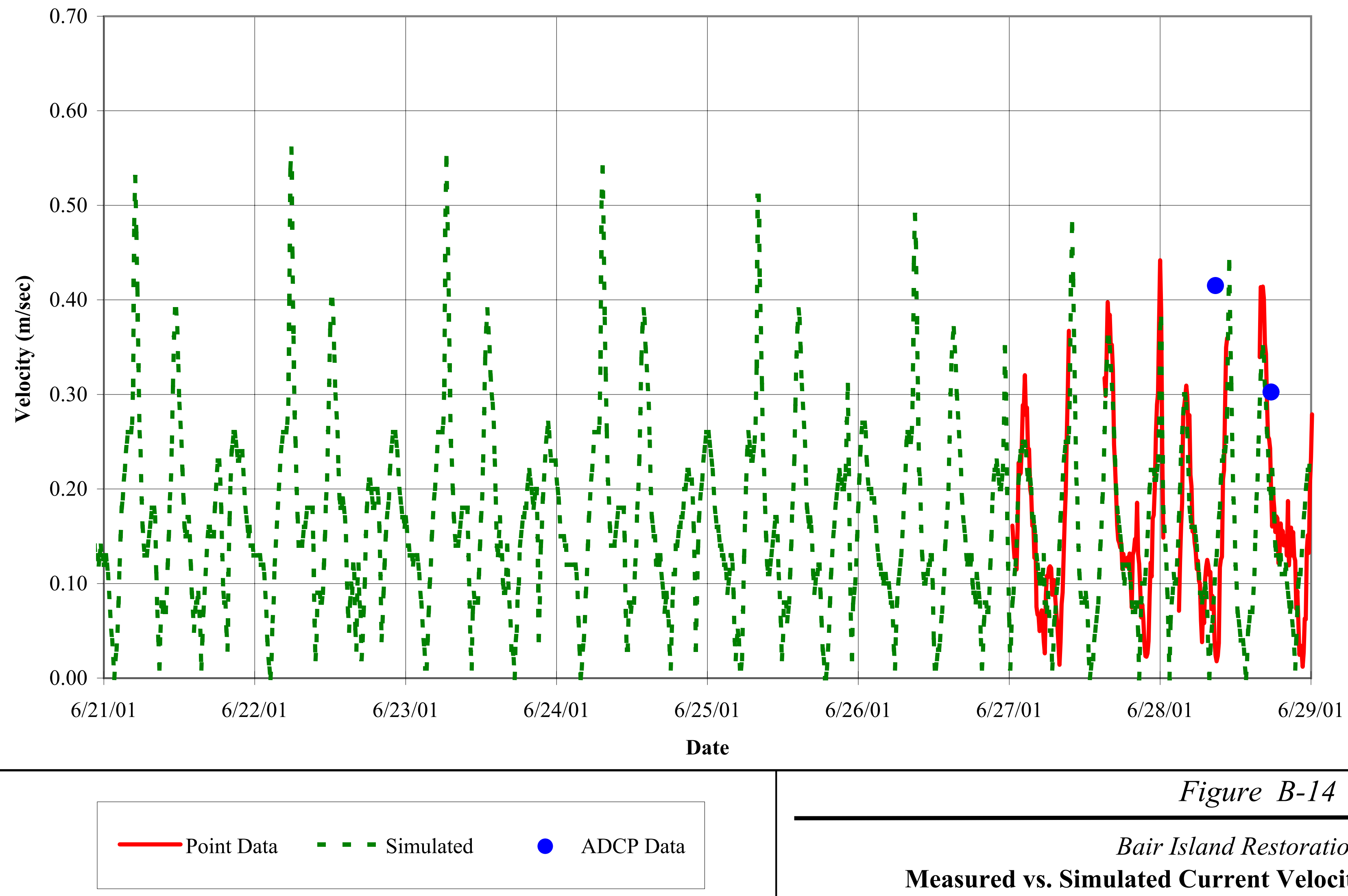
Bair Island Restoration

Measured vs. Simulated Current Velocity

Platform 3

PWA

PWA #: 1413.01



Source: PWA field survey (pt vel measurements) and numerical simulation

Figure B-14

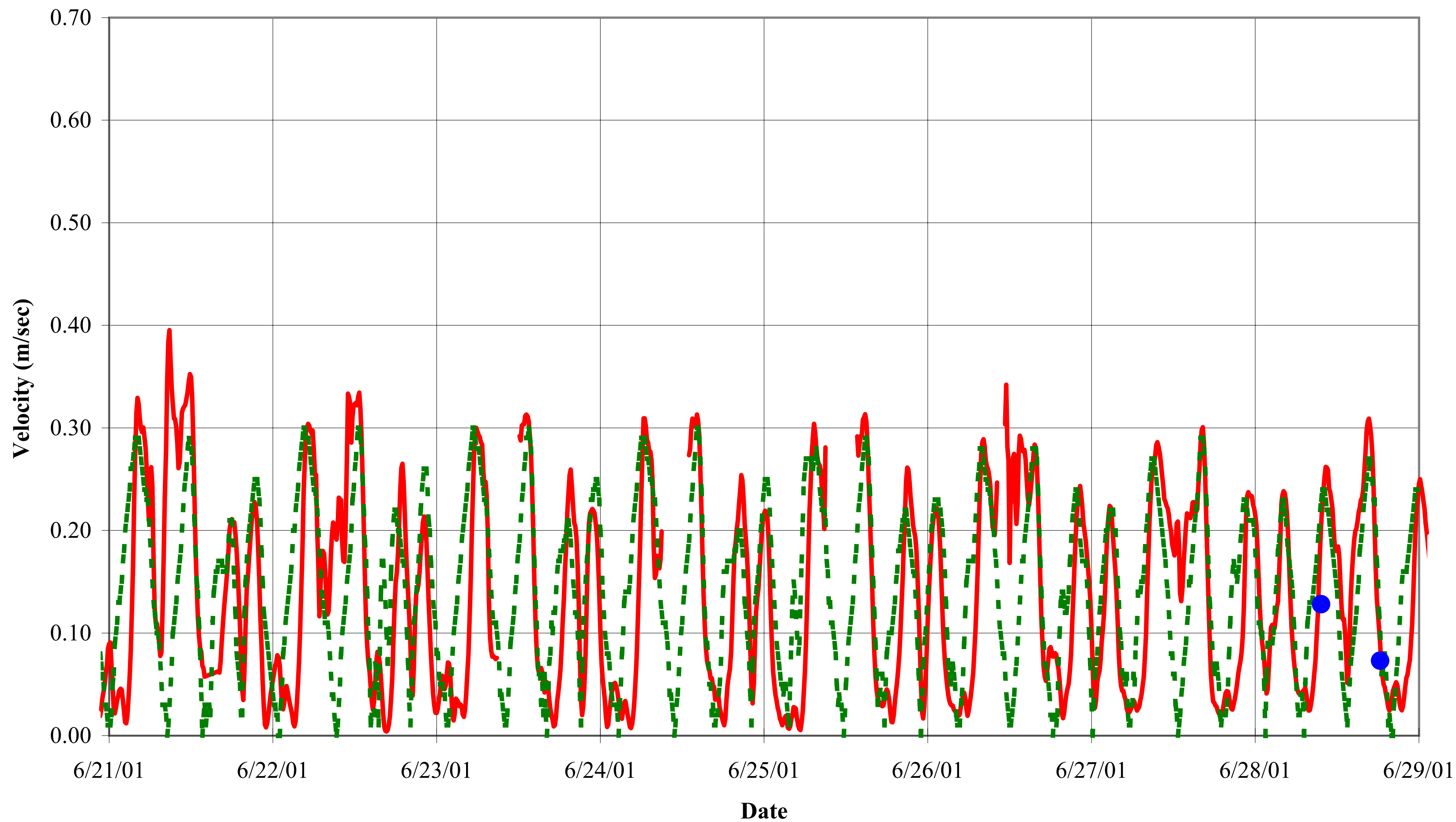
Bair Island Restoration

Measured vs. Simulated Current Velocity

Platform 4

PWA

PWA #: 1413.01



Source: PWA field survey (pt vel measurements) and numerical simulation

Figure B-15

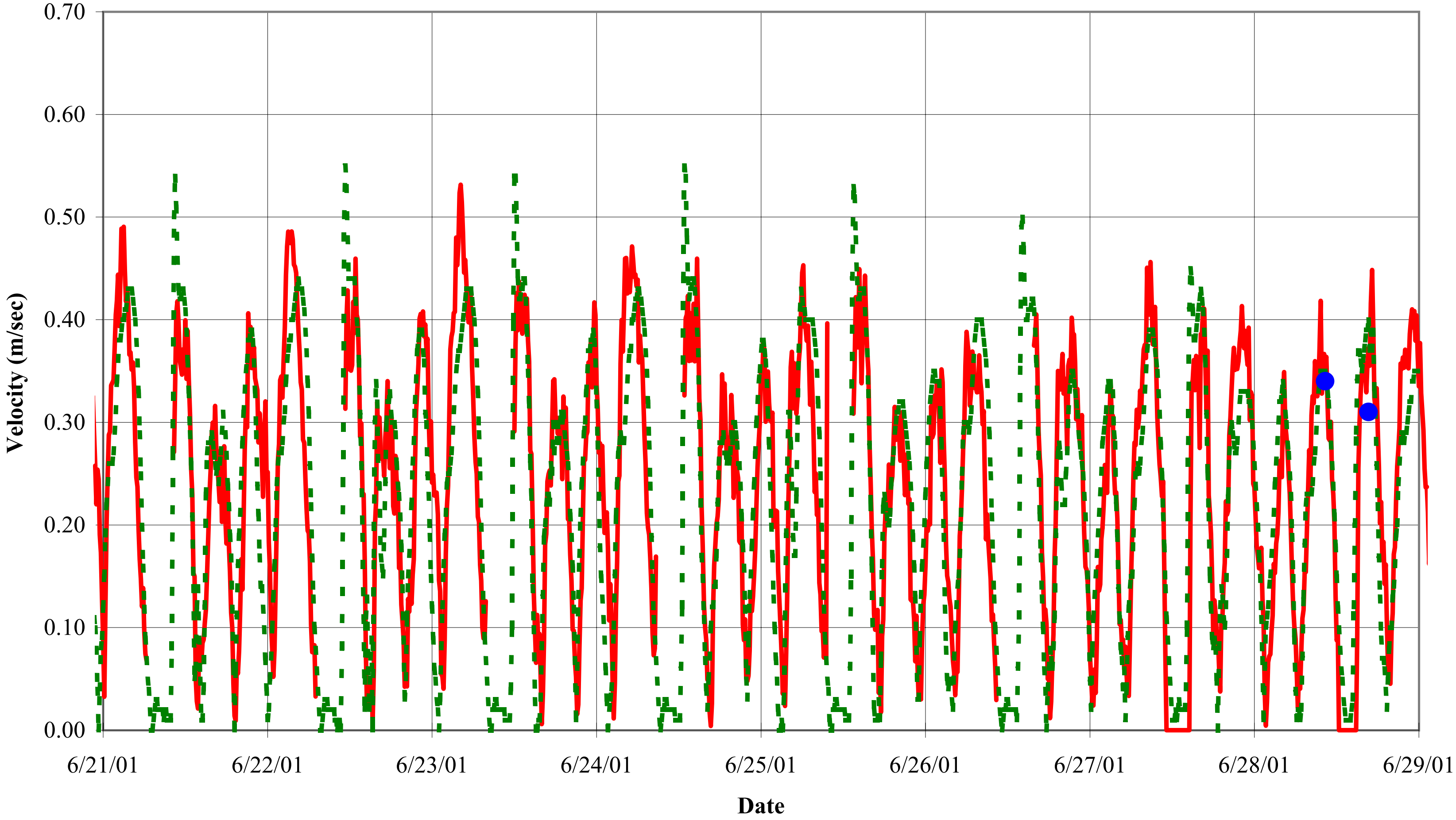
Bair Island Restoration

Measured vs. Simulated Current Velocity

Platform 5

PWA

PWA #: 1413.01



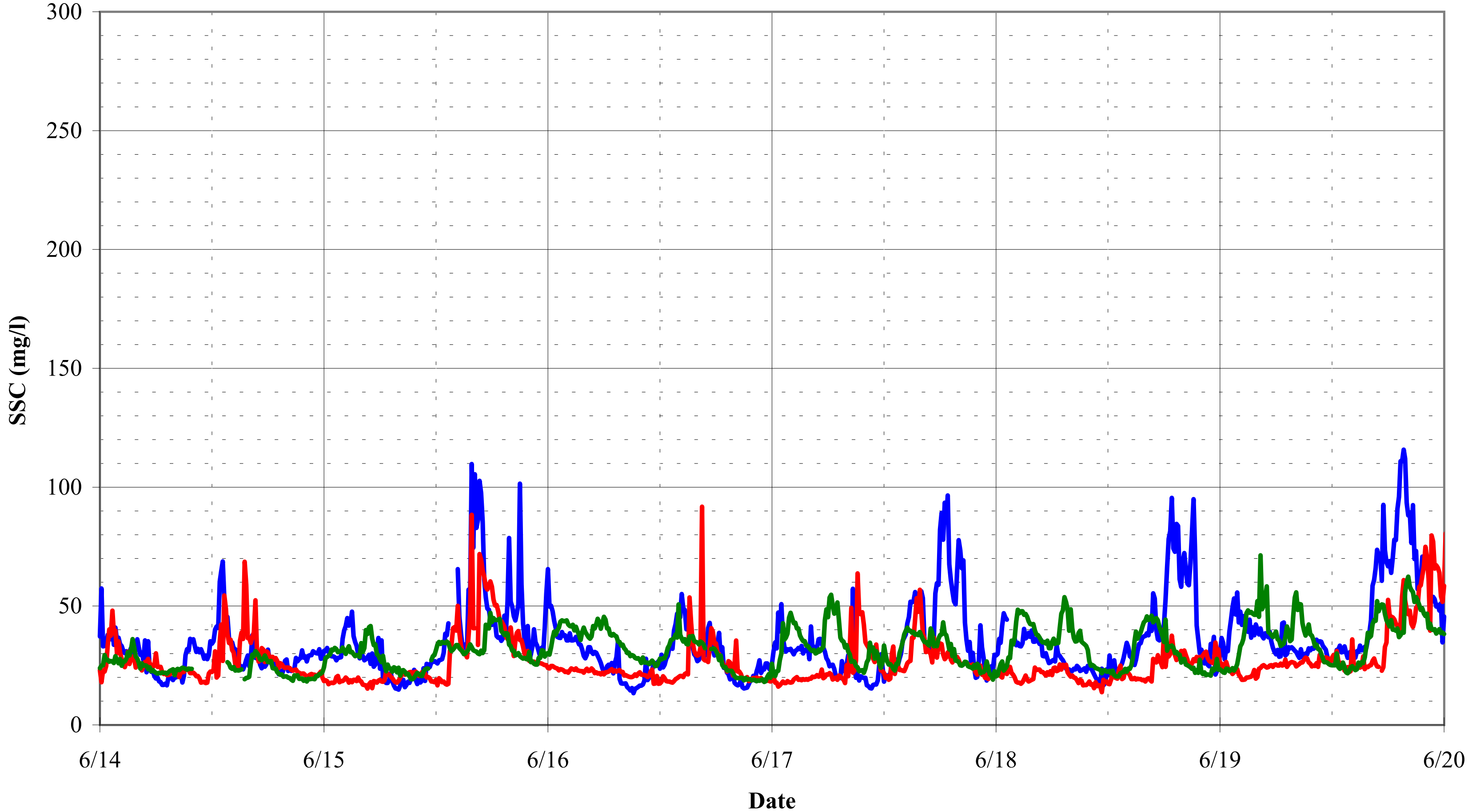
Source: PWA field survey (pt vel measurements) and numerical simulation

Figure B-16

Measured vs. Simulated Current Velocity
Platform 6

PWA

PWA #: 1413.01



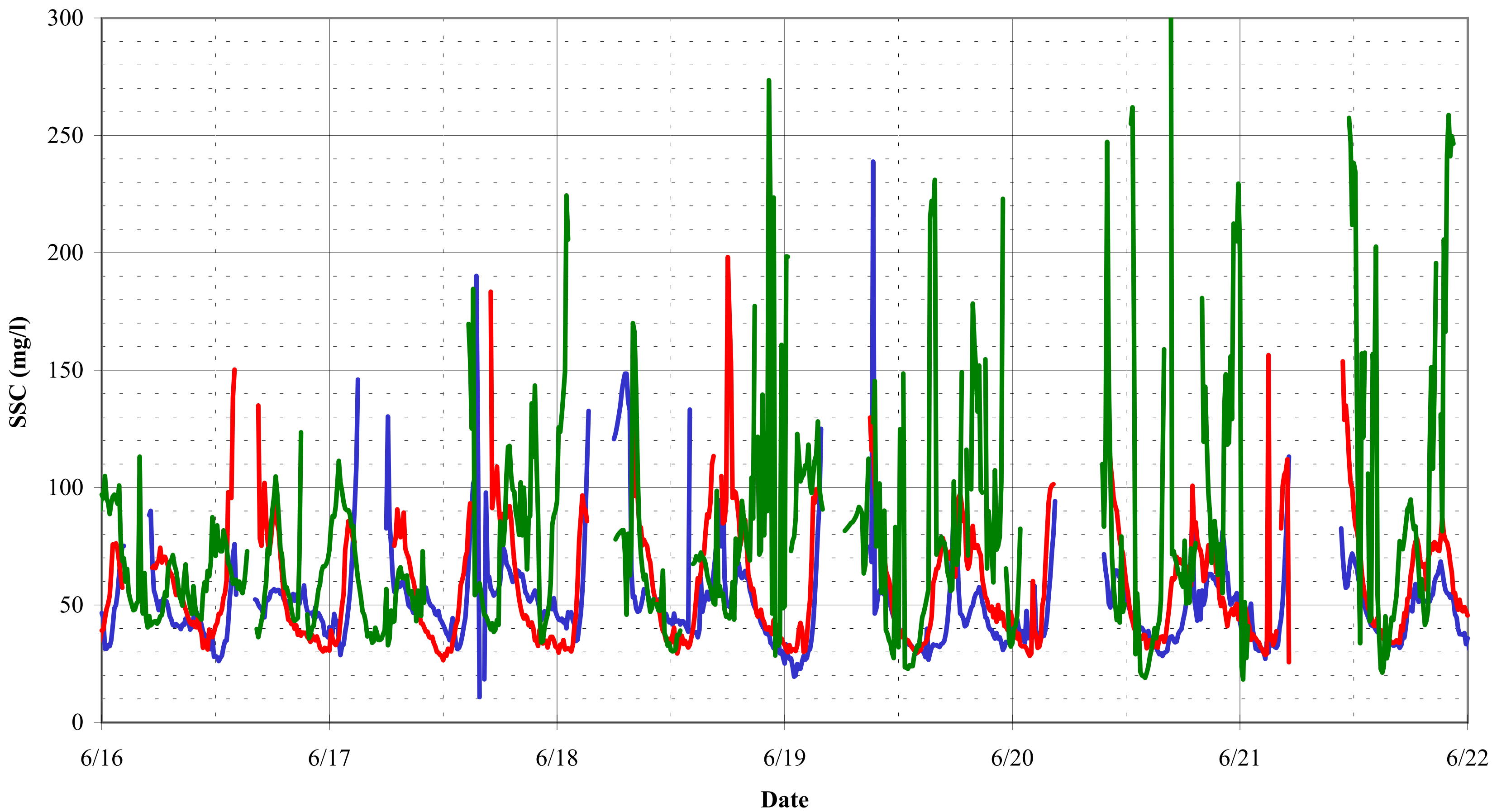
Source: PWA field survey

Figure B-17

Suspended Sediment Concentrations
Platforms 1, 2 and 3

PWA

PWA #: 1413.01



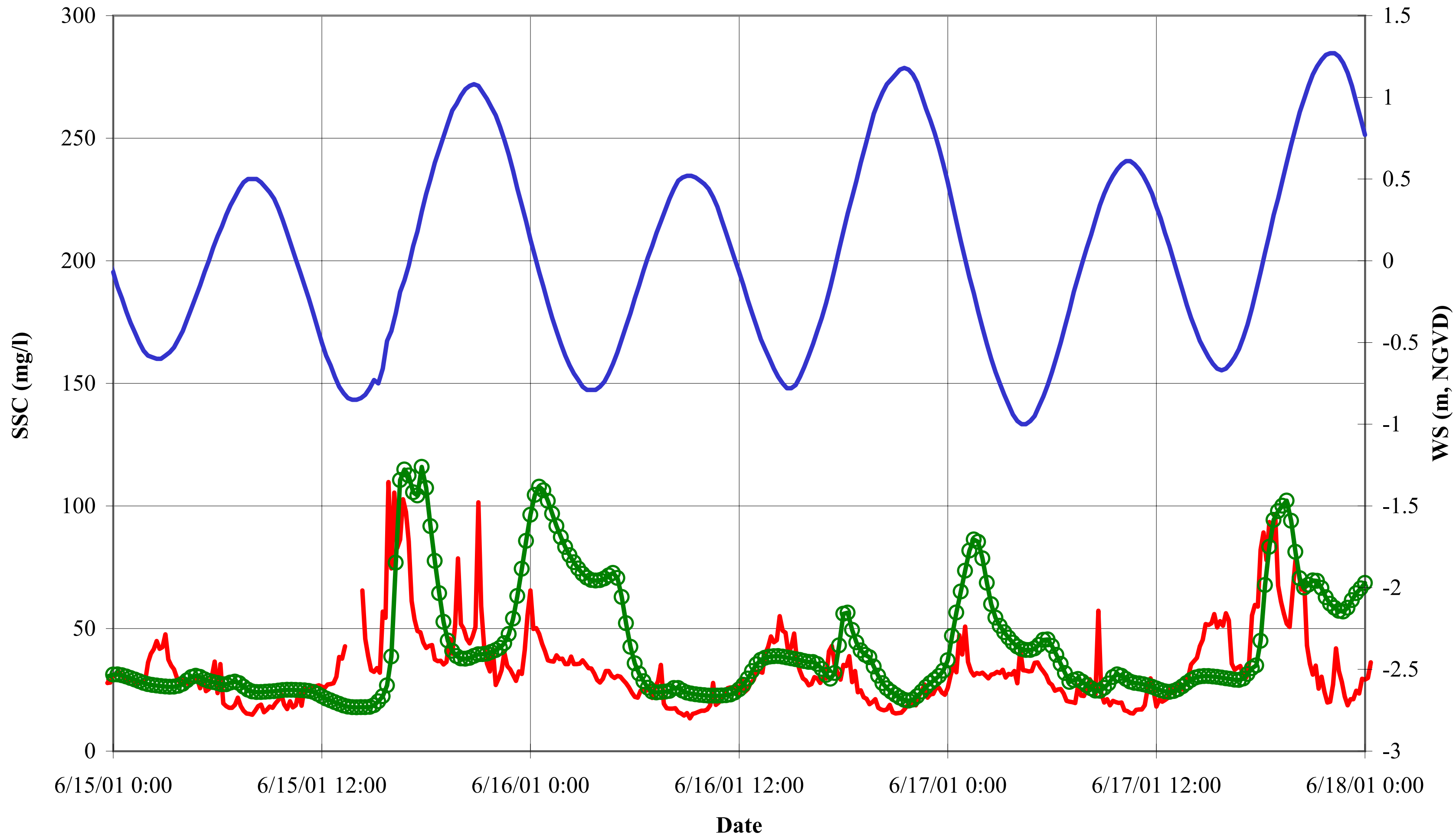
Source: PWA field survey
Note: Signals noisy at low tide due to shallow water depth

Figure B-18

**Suspended Sediment Concentrations
Platforms 4, 5 and 6**

PWA

PWA #: 1413.01



Source: PWA field survey

Figure B-19

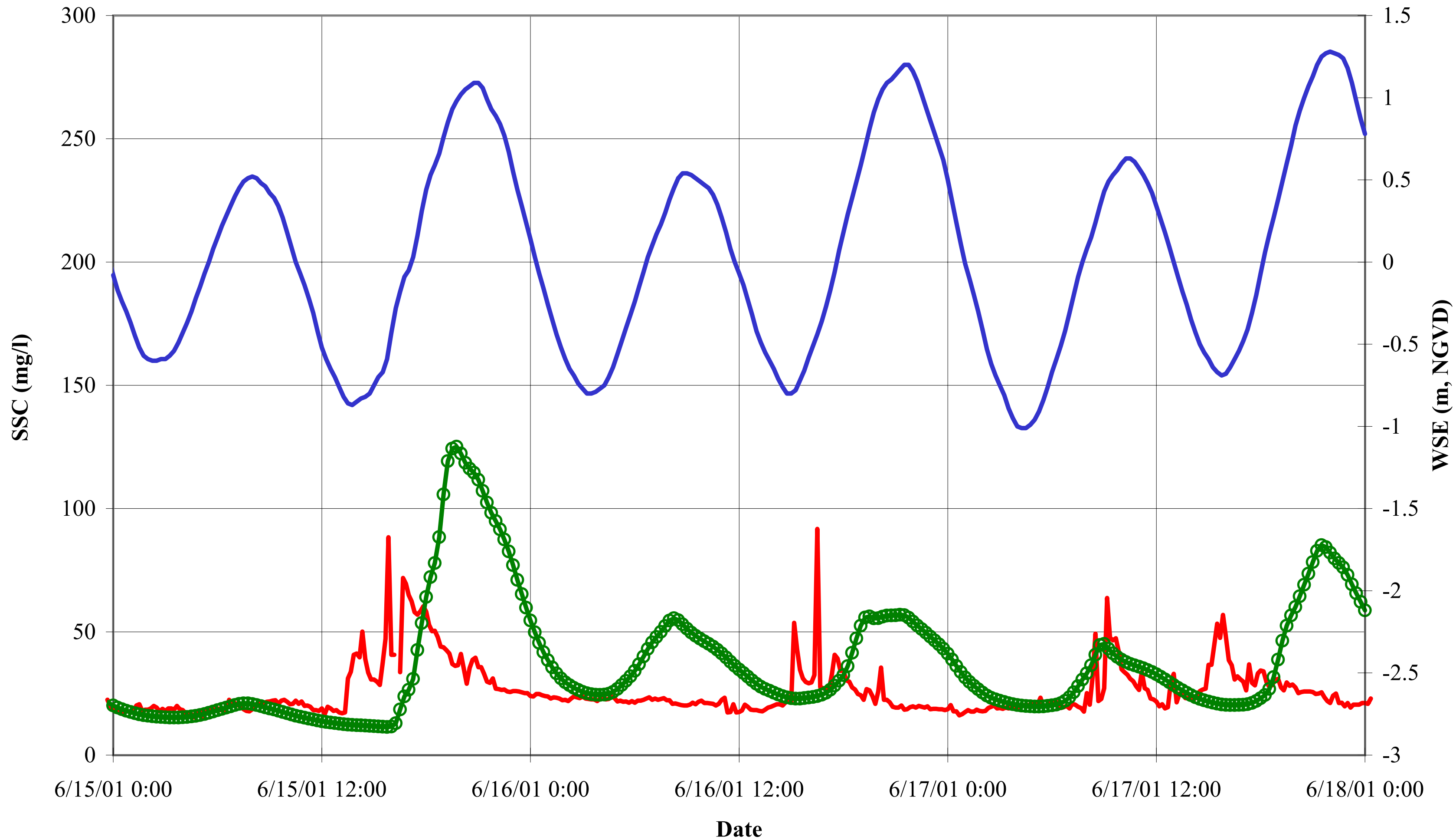
Bair Island Restoration

Suspended Sediment Concentrations

Platform 1

PWA

PWA #: 1413.01



Source: PWA field survey

Figure B-20

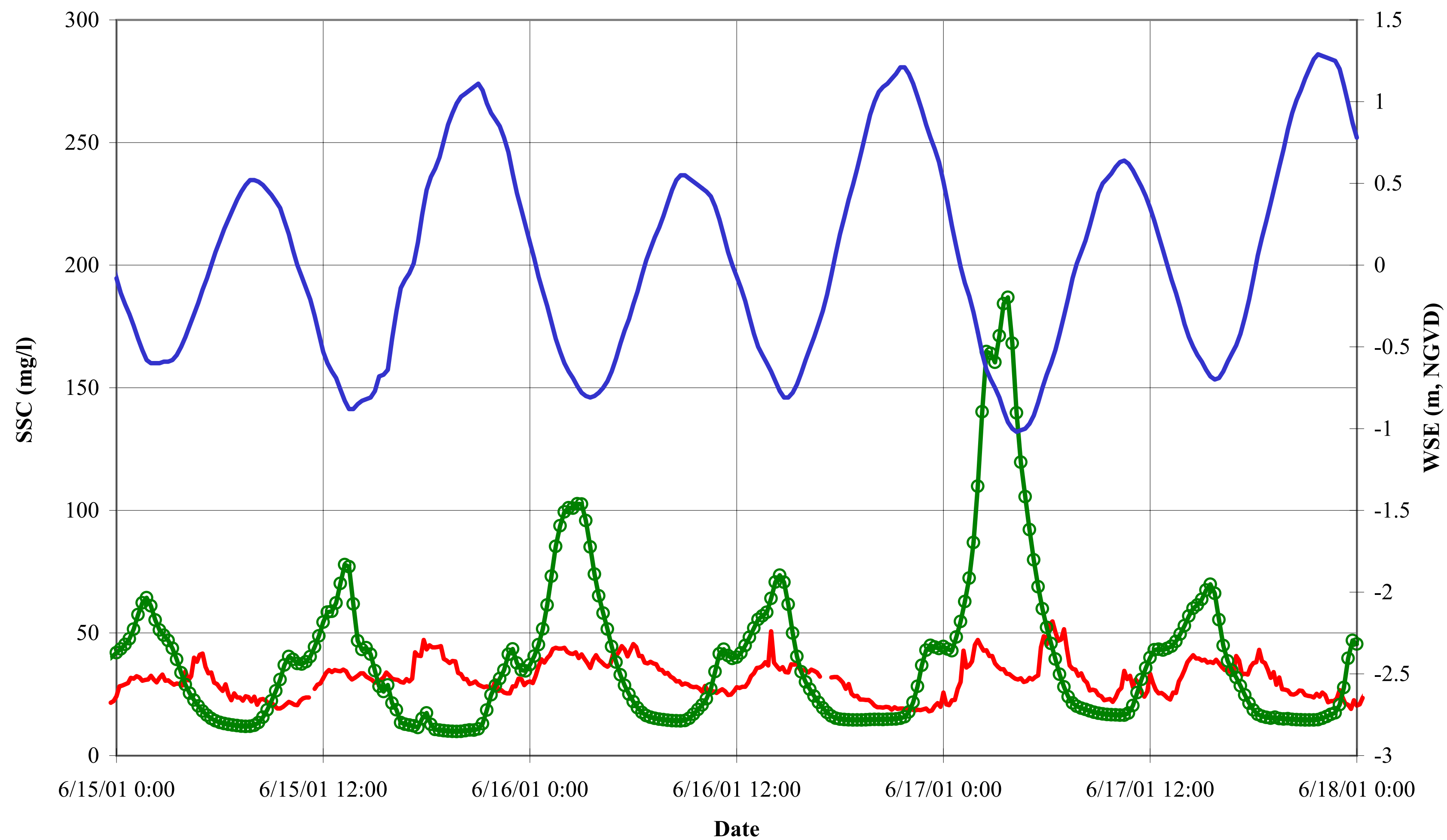
Bair Island Restoration

Suspended Sediment Concentrations

Platform 2

PWA

PWA #: 1413.01



Source: PWA field survey

Figure B-21

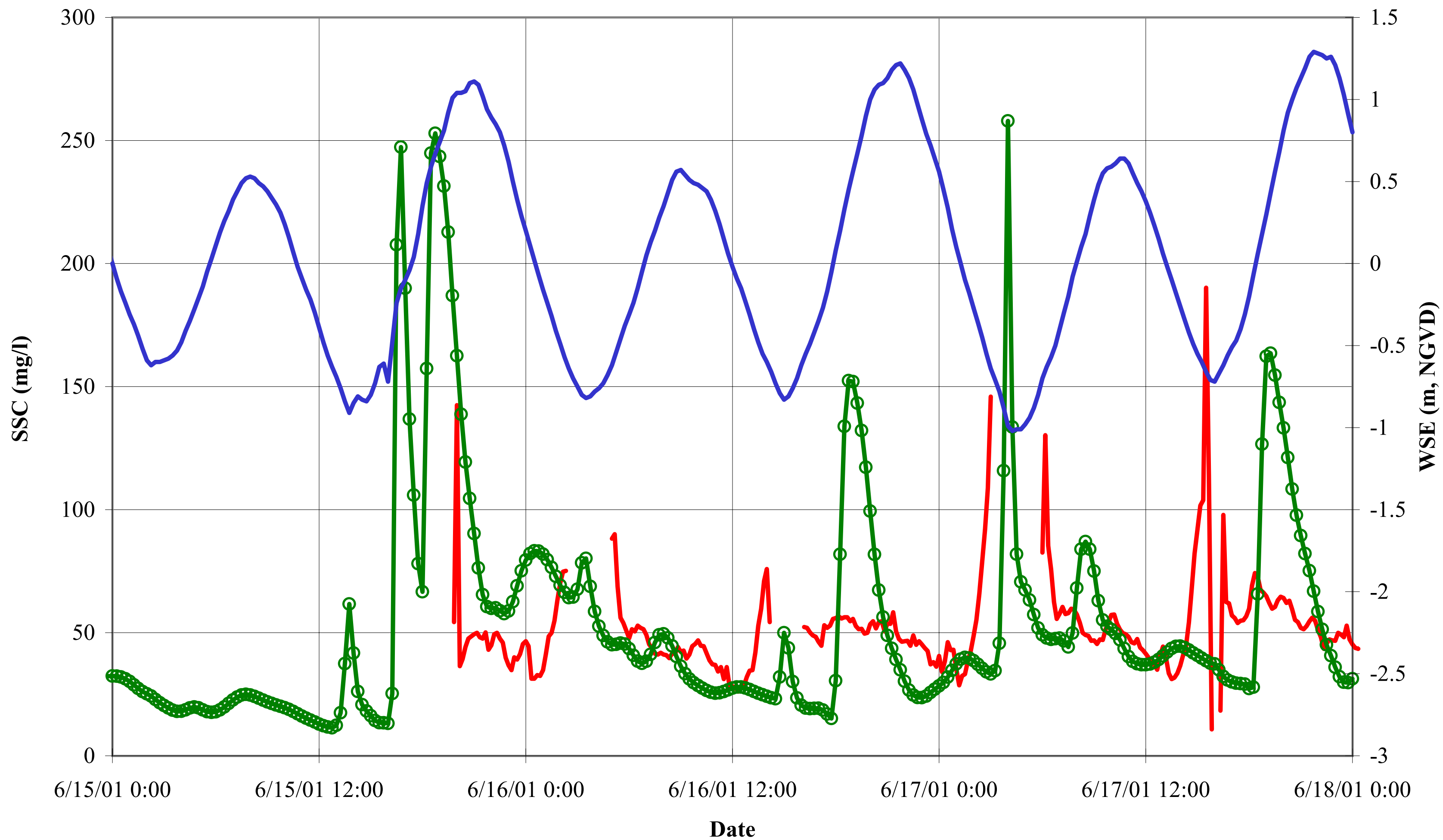
Bair Island Restoration

Suspended Sediment Concentrations

Platform 3

PWA

PWA #: 1413.01



Source: PWA field survey

Note: Signals noisy at low tide due to shallow water depth

Figure B-22

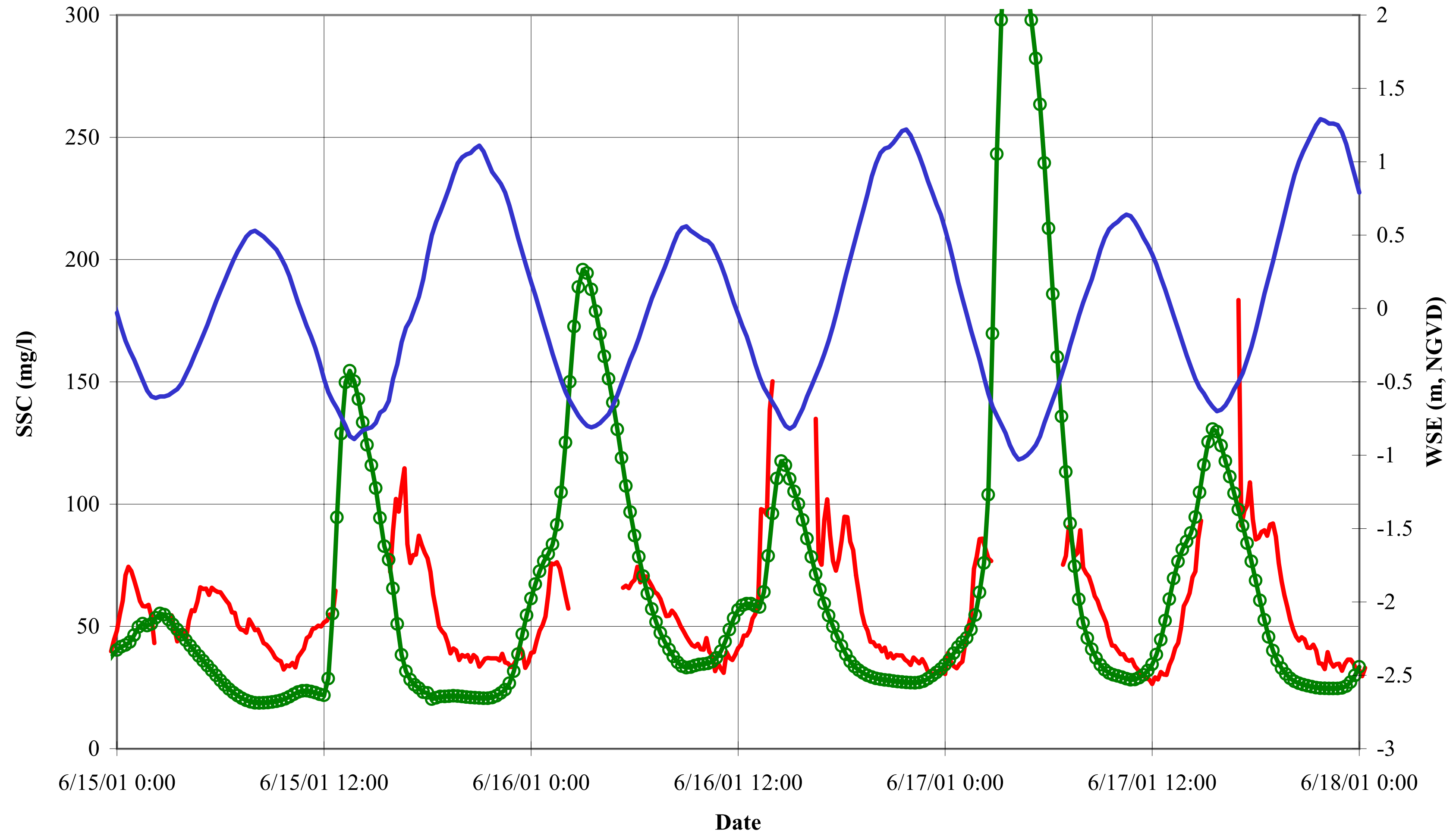
Bair Island Restoration

Suspended Sediment Concentrations

Platform 4

PWA

PWA #: 1413.01



Source: PWA field survey
Note: Signals noisy at low tide due to shallow water depth

Figure B-23

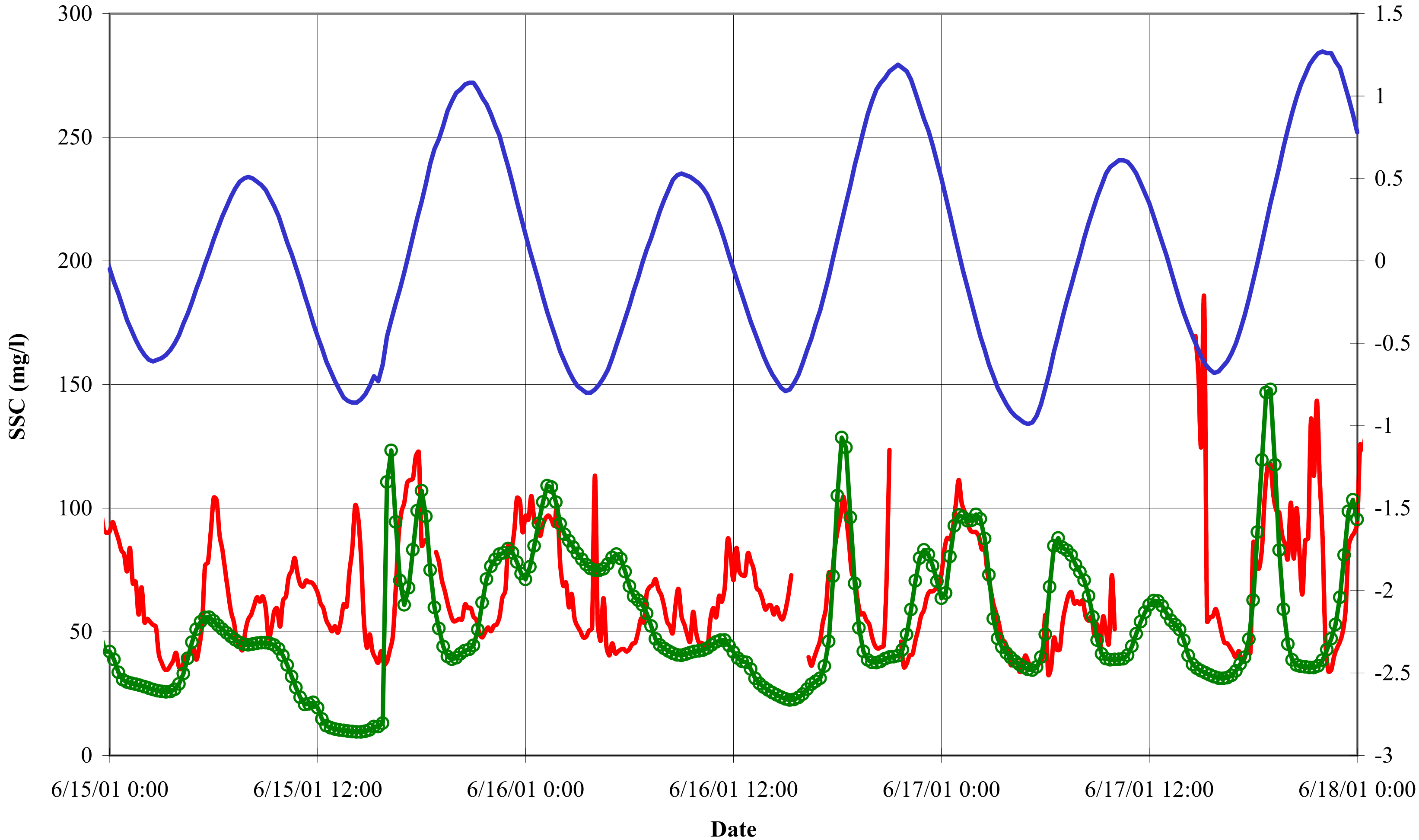
Bair Island Restoration

Suspended Sediment Concentrations

Platform 5

PWA

PWA #: 1413.01



Source: PWA field survey
Note: Signals noisy at low tide due to shallow water depth

Figure B-24

Bair Island Restoration
Suspended Sediment Concentrations
Platform 6

PWA

PWA #: 1413.01

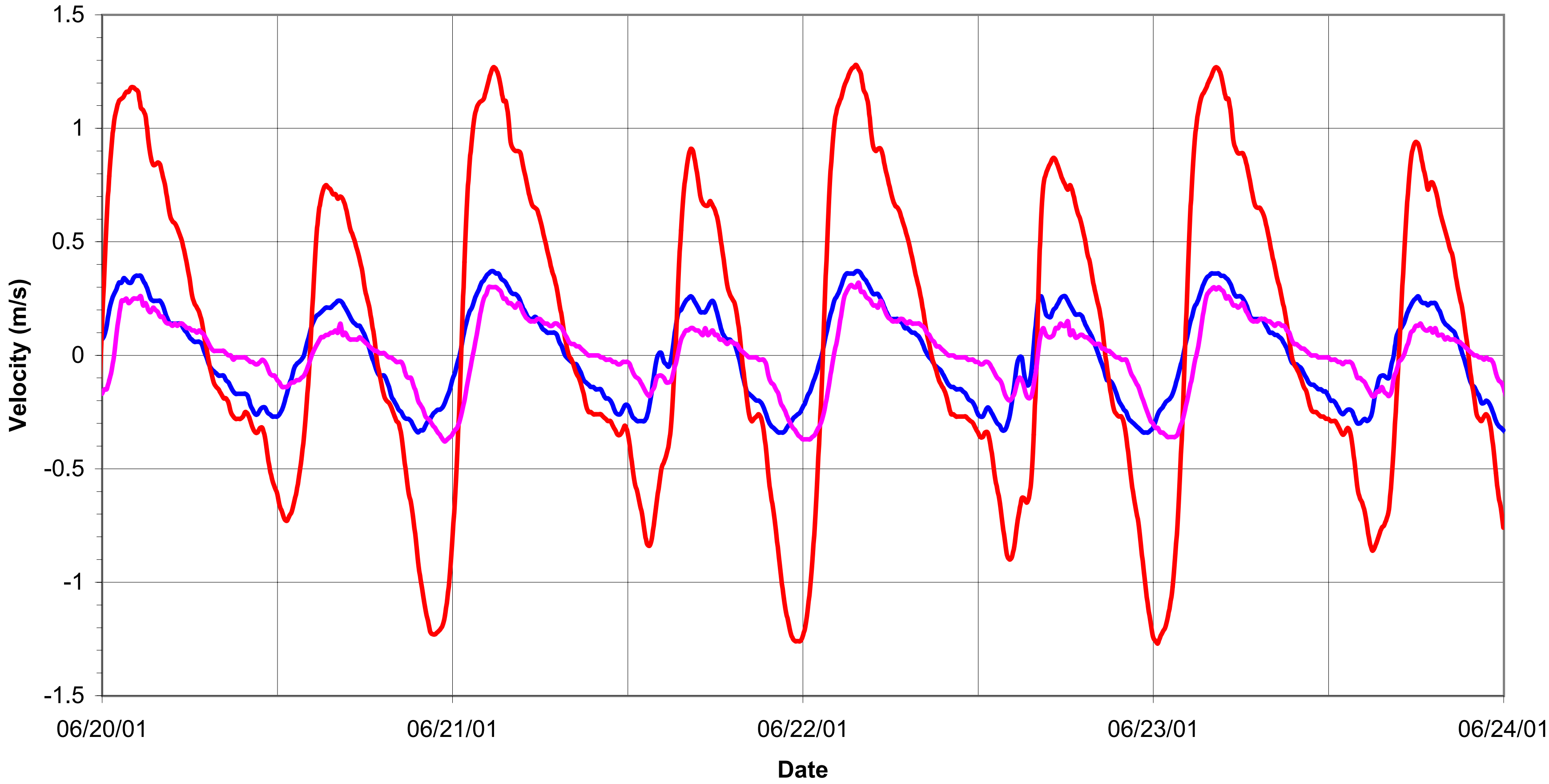


Figure B-25

Bair Island Restoration

Modeled Velocity at Pete's Harbor

PWA

PWA #: 1413.01

C:\DonD\JOBS\1413_BairIsland\RecALt\BigSmithA-25_PetesVelocity-allRUNS.xls

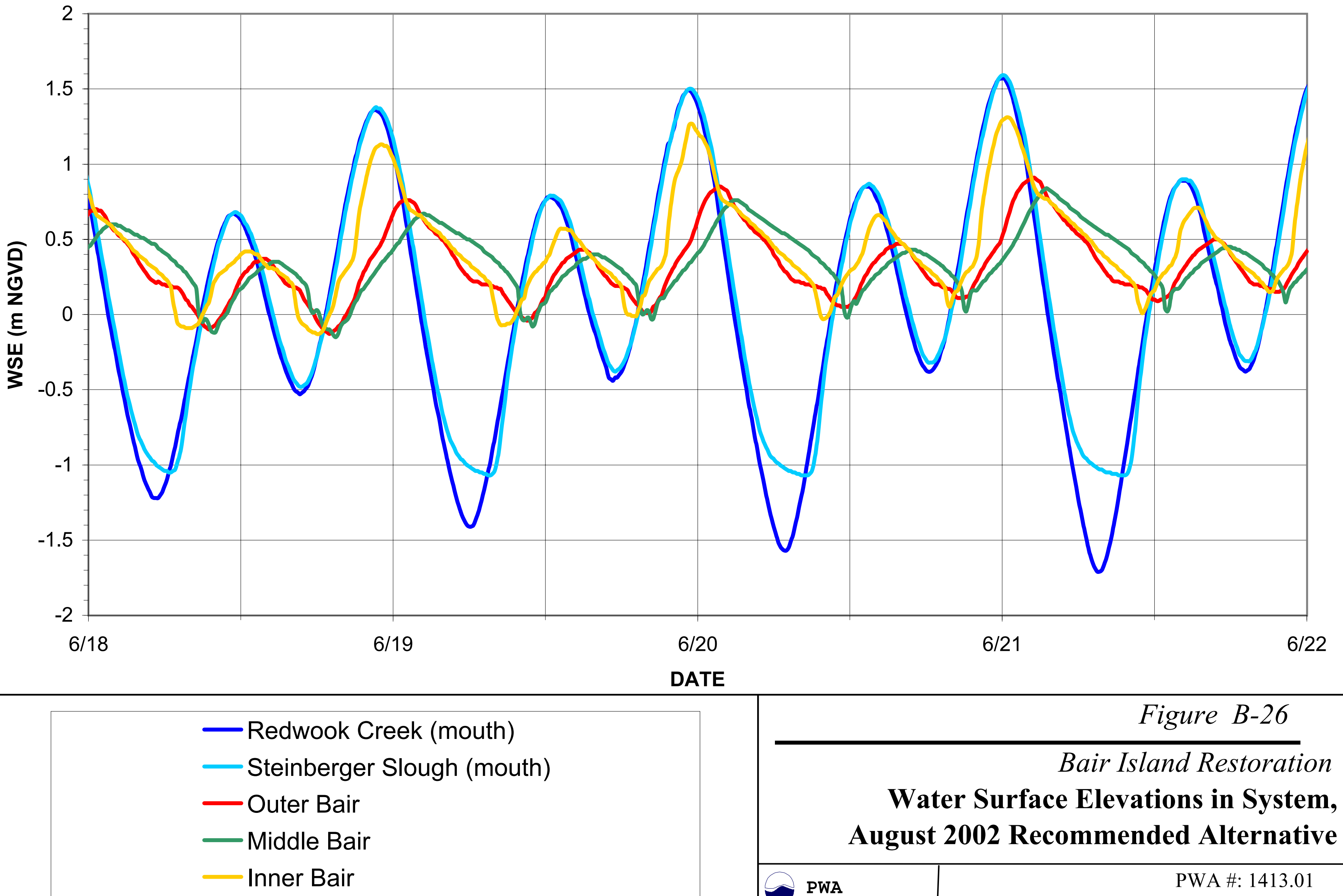


Figure B-26

Bair Island Restoration

Water Surface Elevations in System, August 2002 Recommended Alternative

PWA

PWA #: 1413.01

P:\Projects\1413.01 Bair II\Task_11.3_Modeling\SedXportA-26_WSEinISLANDS-RUNS3-9-15.xls

APPENDIX C.
BIRD STRIKE CONSTRAINTS
AND DESIGN CRITERIA

BIRD-STRIKE ISSUES AT INNER BAIR ISLAND

Inner Bair Island is adjacent to San Carlos Airport, which lies immediately to the northwest (Figure 1). A portion of Inner Bair Island is within the San Carlos Airport Safety Zone (SCASZ), in line with the airport runway. Concern has been expressed by San Carlos Airport about the potential for restoration activities at Inner Bair Island to increase bird use of the area, thereby increasing the possibility of bird-strikes in the SCASZ.

The FAA Advisory Circular number 150/5200-33 recommends a distance of 5,000 feet between the airport and new wildlife attractants such as wetlands. The circular also provides for exceptions to the recommended distance when the wetland in consideration provides "unique ecological functions, such as critical habitat for threatened or endangered species." The goal of the Bair Island restoration project is to provide habitat for the California Clapper Rail and the salt marsh harvest mouse, and therefore clearly falls within the outlined exceptions. In addition, the airport is surrounded by existing aquatic and wetland habitat that already serves as an attractant to wildlife. However, we are concerned about the potential for bird strikes at San Carlos airport, and have been in communication with airport personnel, as well as the FAA and USDA Wildlife Services to work to minimize the attractiveness of Inner Bair Island within the SCASZ to wildlife that pose the greatest threat to airport safety.

Design criteria for the restoration of Inner Bair Island have largely been driven by these concerns. As a result, the preferred alternative outlined in the body of this report includes a levee around the entire airport safety zone, thereby not allowing tidal action into that area and the conversion of that area to uplands by the use of dredge spoil. The particulars of the implementation, which take into account every foreseeable feature that might attract birds, is summarized in Section 7.7.3. The evolution of tidal marsh on the remainder of Inner Bair will be accelerated by the beneficial use of dredged material to raise the marshplain elevation to reduce the amount of open water and expedite the formation of emergent marsh. The resulting wetland system should actually be less attractive to wildlife species that pose the greatest threat to aircraft at San Carlos Airport.

BACKGROUND INFORMATION ON BIRD-STRIKES

The FAA annually compiles bird-strike data from airports around the United States (Cleary et al. 2002). Between 1990 and 2001, 39,177 bird-strikes resulting in six fatalities were reported to the FAA. Most strikes occurred during approach or on the take-off run, and most strikes occurred on the ground (41%), or below 100 ft. (14%). Most strikes occurred in late summer or fall. 9% of all strikes in the U.S. occurred in California.

We summarized bird strike data (Cleary et al. 2002) for those species that are likely to occur in the San Francisco Bay area (Table 8). It should be noted that a large percentage of wildlife strikes are also caused by mammals, particularly deer. The greatest concern is to avoid bird-strikes that cause an effect-on-flight (EOF) of the aircraft. The majority of strikes causing EOF were with gulls (*Larus* spp.), followed in frequency by waterfowl and raptors. Strikes with waterfowl were most likely to cause injury, followed by raptors and gulls.

Table 8. Bird-strike Data 1990-2001 for Species Likely to Occur in the San Francisco Bay Area, from Cleary et al. (2002).

Bird Taxa	Strikes Resulting in EOF	Strikes Resulting in Damage	Strikes Resulting in Injury or Fatality	Total Number of Strikes
Gulls	624	782	7	4501
Waterfowl	395	837	31	1834
Raptors	274	443	16	1996
Blackbirds	69	66		873
Starlings	55	41		876
Herons & Egrets	54	60	1	448
Sparrows	48	27		1204
Shorebirds	38	29		672
Crows and Jays	28	33		310
Owls	20	42	1	368
Swallows	16	9		513
Pelicans	10	15	1	26
Meadowlarks	9	4		227
Cormorants	3	8	1	20
Loons and Grebes	2	4	1	7
Rails and Coots	1	3	1	20
Terns	1	4		46

Data area sorted by strikes resulting in effect-on-flight (EOF).

CURRENT POTENTIAL FOR BIRD STRIKES AT SAN CARLOS AIRPORT

The channel between San Carlos Airport and Inner Bair Island (approximately 50 m across) provides some habitat for waterfowl and gulls, primarily in winter. The margins of this channel also provide foraging habitat for shorebirds, and herons and egrets. This habitat is closest to the runway, thus wildlife here pose the greatest threat to aircraft during low-elevation approach or take-off. South of this channel, Inner Bair Island is predominantly ruderal grassland. Bird species using this habitat include raptors (e.g., Red-tailed Hawks and Turkey Vultures) and songbirds (e.g., swallows). Raptors currently pose a bird-strike threat in this habitat. In addition, ponding within the SCASZ on Inner Bair Island does occur each winter.

Between September 1990 and September 1999, there have been 39 bird strikes recorded at San Carlos Airport (FAA files, as of June 13, 2001 as reported in the San Carlos Master Plan EIR). The majority of these strikes took place on or over the runway, and not over Inner Bair Island. In addition, most of the strikes involved pigeons (28 of the 39 reported strikes), and not birds associated with the nearby wetland or aquatic habitats. Other birds struck included gulls (4), Canada geese (3), ducks (1) and three (3) unknown birds. These strikes resulted in a total of 6 precautionary landings and 3 aborted takeoffs, while the rest of the strikes had no effect on the flight of the aircraft (San Carlos Master Plan EIR).

However, in conversations with airport personnel, it appears that bird strikes may occur more frequently than are reported. Anecdotal accounts indicate that an incident involving a bird occurs approximately once every two weeks. Gulls were indicated as the bird of primary concern to airport personnel.

In addition, the Sequoia Audubon Society conducts bird surveys of Inner Bair Island. During their surveys from December 2000 to August 2001, the survey personnel were asked to note any time a bird was flushed during landing or take off of a plane at San Carlos Airport. The only birds in the vicinity of the airport observed as flushing were 6 pairs of mallards (two pairs from Pulgas Creek, and 3 pairs from the area between Inner Bair and Highway 101) and numerous Canada Geese on one occasion from Inner Bair Island.

POTENTIAL FOR BIRD STRIKES AFTER RESTORATION

Restoration of Inner Bair Island will not affect the channel between the airport and inner Bair Island, or the northern portion of Inner Bair Island that is to be used as an emergency landing area for San Carlos Airport. Bird communities in these areas will not be affected. The SCASZ will be leveed and filled to an elevation that supports upland habitat, thereby reducing the amount of winter ponding in those portions of Inner Bair Island closest to the runway.

The remainder of Inner Bair Island will be restored to tidal salt marsh. Bird communities are expected to shift immediately after tidal action is restored. Small shorebirds are likely to use newly inundated areas for foraging, and as vegetation develops over the next several years, the bird community will likely shift to low numbers of rails, large shorebirds, and herons and egrets. This habitat is not likely to support songbirds or raptors. Thus, the restoration of Inner Bair Island to tidal salt marsh has the potential to reduce bird-strikes near San Carlos Airport by reducing the number of raptors, gulls and waterfowl using the area.

APPENDIX D.
DOG USE MONITORING PROGRAM

DOG USE MONITORING PROGRAM FOR INNER BAIR ISLAND

PURPOSE

The purpose of monitoring visitor compliance with the Refuge's established Dog Rules is to determine whether allowing dogs on Inner Bair Island will cause unacceptable impacts to wildlife, including endangered species, and Refuge visitors. It is assumed that if dog owners follow the Refuge's established rules for dogs, the dogs will not cause unacceptable impacts.

DOG RULES

1. Dogs will be on a 6-foot leash;
2. Dogs will stay on the established trails; not in vegetation or in water;
3. Owners will pick up their dogs' waste;
4. Dogs will be under control; not jump on, bark at, or otherwise disturb Refuge visitors.

PROTOCOL

Refuge Staff and Volunteers in uniform will conduct a one-month outreach period before the test is started to inform Bair Island visitors of the dog rules.

Compliance with the Bair Island dog rules will then be tested for a 3-month period. Refuge staff without uniforms will walk the Inner Bair Island trails four times a week for 2 hours each visit. The visits will be made at various times of the day and week. During each week, three compliance checks will be made on weekends when Bair Island receives most of its visitation and one compliance check will be conducted on a weekday. Compliance checks will be rotated among morning and afternoon/evening hours, with a focus on before and after work hours when visitation on weekdays is the highest. Therefore, data will be compiled for weekend and weekday mornings, afternoons/evening periods (i.e., Week One: Compliance checks will be done on Sunday morning, Sunday afternoon/evening, Monday morning, and Saturday morning. Week Two: Compliance checks will be done Sunday afternoon/evening, Tuesday afternoon/evening, Saturday morning and afternoon/evening.). Staff will record the number of owners with dog(s). If any of the owners' dog(s) are seen violating the dog rules, it will be recorded and the data filed at Refuge Headquarters.

COMPLIANCE STANDARD

No research has been done on disturbance of wildlife by dogs at Bair Island. However, observations of dog disturbance of wildlife at other locations indicates that it is highly likely that dogs can have a detrimental impact on wildlife. On numerous occasions at the Corte Madera Ecological Preserve, clapper rails have been observed seeking refuge from dogs entering tidal marshes from adjacent levees with public access (USFWS 1997). Dogs have been documented to be a disproportionate source of disturbance of wildlife near Devereux Slough in Santa Barbara County (Lafferty 2001). Impacts from disturbance range from lethal to reduced opportunities to forage or rest, which could have cumulative impacts on reproduction and survivorship. Because of the lack of research addressing the issue, it is not possible to pinpoint what level of disturbance of wildlife would be acceptable. However, because of the anticipated presence of endangered species in the restored tidal marshes of Inner Bair Island, the disturbance threshold must be conservative.

The USFWS believes that more than one dog being off the trail each day would cause an unacceptable disturbance to wildlife, including endangered species. The USFWS also believes that more than 2 dogs per day not using a 6-foot leash, disturbing Refuge visitors, or not having their waste picked up will cause unacceptable impacts to wildlife and/or Refuge visitors.

Bair Island Visitor Use Surveys estimated that 250,000 people visit Inner Bair Island each year. Thirty-eight percent (38%) of these visitors bring at least one dog which results in a minimum of 95,000 dog visits each year or 260 dogs per day. One dog off the trail each day would result in a minimum of 365 dog impacts to Refuge wildlife each year and would amount to approximately 0.5% of the dogs using the Refuge trail. If two dogs per day are off their leash, disturbing visitors and/or not having their waste picked up, that will result in a minimum of 730 impacts to wildlife/visitors per year or approximately 0.76% of the dogs using the Refuge trail. Therefore, the maximum percentage of dog owner violations that would be acceptable during the test period would be 0.5% for dogs off the trail and 0.76% for dogs not using a 6-foot leash, disturbing Refuge visitors, or not having their waste picked up. The percentage will be calculated by dividing the number of dog violations by the number of visitors with dogs. A group of visitors walking one dog will be counted as one owner with a dog. A visitor with multiple dogs will be counted as one owner with a dog. Any of these owners seen allowing the dogs to violate the rules would be counted as one violation.

RETEST OPTION

If the Dog Use Monitoring Program demonstrates that dog owners are meeting the compliance standard, dog use will continue to be allowed on Inner Bair Island. If, at a later date, the Refuge Manager believes that compliance with the dog rules has declined, the Refuge will conduct another dog use outreach and monitoring program. Based on the results of this later test, the Refuge may continue to allow dog use or close Bair Island to dog use.

APPENDIX E.
LONG-TERM SEDIMENTATION MODELING

BAIR ISLAND RESTORATION AND MANAGEMENT PLAN
APPENDIX E

LONG TERM SEDIMENTATION MODELING

1.0 INTRODUCTION

The FORTRAN program "MARSH98" estimates the long term sedimentation of constructed and natural marshes and marshplains. The program, proprietary to PWA, utilizes Krone's (1987) approach of marshplain modeling.

2.0 BACKGROUND

According to Krone (1987), the elevation of a marshplain rises at rates that depend on the (1) availability of suspended sediment and (2) depth and periods of inundation by high tides. When the level of an evolving marsh surface is low with respect to the tidal range, sedimentation rates may be high if the suspended sediment supply is ample. However, as the marsh surface aggrades through the tidal range, the frequency and duration of flooding by high tides is diminished so that the rate of sediment accumulation declines.

As laid out by Krone (1987), MARSH 98 calculates the amount of suspended sediment that deposits during each period of tidal inundation and sums that amount of deposition over the period of record.

3.0 METHODS

MARSH 98 is based on methods devised by Professor R.B. Krone of UC Davis and reported in his 1987 paper (Krone, 1987). The algorithm is centered around the mass balance of suspended sediment throughout the water column. The equation for this balance is:

On the flood tide when $\frac{d\eta}{dt} \geq 0$,

$$(\eta - z)\frac{dC}{dt} = -V_s C + (C_o - C)\frac{d\eta}{dt}$$

On the ebb tide when $\frac{d\eta}{dt} < 0$,

$$(\eta - z)\frac{dC}{dt} = -V_s C$$

where:

η = Water surface elevation,

z = Marshplain elevation,

C = Suspended sediment concentration,

t = Time,

V_s = Settling velocity, and

C_o = Ambient suspended sediment concentration of flood laden waters.

The major underlying assumption with the mass balance equation is that all material that settles to the bed becomes permanent marshplain material and is not scoured by ebb currents, large waves, or storm conditions. The settling velocity for suspended particles has the following relationship:

$$V_s = KC^{4/3}$$

where:

V_s = Settling velocity,

K = A constant (0.00011 when units are S.I. Metric), and

C = Suspended sediment concentration.

Accumulation of material on the bed is determined by the following equation:

$$\Delta z = \frac{\int V_s C dt}{C_d}$$

where:

Δz = Change in bed elevation,

V_s = Settling velocity,

C = Suspended sediment concentration, and

C_d = Dry density of inorganic material in the deposit.

On the flood tide, the storage of suspended sediment in the water column is affected by (1) re-supply from the sediment laden flood waters (inflow), and (2) deposition to the marsh surface (outflow)— the suspended sediment concentration is affected by both of these processes. On the ebb tide, the storage is affected by (1) ebb waters that remove sediment (outflow), and (2) deposition on the marsh surface (outflow)— the suspended sediment concentration is only affected by the depositional process. MARSH98 can perform the mass balance when the marsh surface is subtidal (always submerged) or intertidal (submerged only part of the time) and can transition between the two states.

Using a series of successively correcting and approximating half- and full-step advances, the algorithm moves the solution forward through time. The technique is very similar to how a second order Runge-Kutta ODE integrator would integrate the equations and advance the solution in time. The exact numerical recipe is laid out by Krone in his 1987 paper.

4.0 REFERENCES

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APPENDIX F.
EXISTING BIOLOGICAL CONDITIONS ASSESSMENT
(BOUND SEPARATELY)

APPENDIX G.
EXISTING HYDROLOGIC CONDITIONS ASSESSMENT
(BOUND SEPARATELY)

APPENDIX H.
BAIR ISLAND PRELIMINARY FLOOD ASSESSMENT

PWA
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MEMORANDUM

DATE: September 19, 2003

TO: Clyde Morris, USFWS
John Bourgeois, HTH

FROM: Don Danmeier
Michelle Orr

RE: **BAIR ISLAND PRELIMINARY FLOOD ASSESMENT - REVISED**
PWA Ref. 1413 – CM 1+2

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1 INTRODUCTION

Tidal hydrodynamic modeling carried out by PWA during the development of the restoration plan for Bair Island (HTH 2002) showed elevated low tide drainage in the upstream reaches of Steinberger Slough. These elevated low tides were a direct result of re-routing flows within the slough network, which was necessary to meet other project constraints but which has the potential to worsen flooding in the watershed. Therefore, PWA carried out additional numerical modeling of extreme flood events in order to assess the extents of project-related changes to flood hazards along Pulgas and Cordilleras Creeks. This memo summarizes the methods and results from the flood assessment.

2 CONCLUSIONS

The present flood analysis consisted of modeling water levels at the downstream limits of Pulgas and Cordilleras Creeks under various flood events. Previous flood studies for Caltrans and FEMA were reviewed to establish appropriate combinations of bay tides and creek flows. The preliminary flood assessment lead to the following conclusions:

- Short-Term Flood Hazards. Based on the flood modeling, the proposed action is expected to increase peak water levels at Highway 101 by approximately 1.5 cm (0.05 ft; less than an inch) during a 100-year flood event. This estimate is for initial conditions immediately after breaching and is expected to decrease as Steinberger Slough deepens over the first months and years. The magnitude of this change is expected to decrease with distance upstream from

Highway 101, although the flood assessment did not extend to these upstream areas. Increases in peak water levels were less for more frequent flood events (i.e., the 10- and 50-year events).

- Long-Term Flood Hazards. In the long-term, the proposed restoration project is expected to increase peak flood water levels by 1.2 cm (0.04 ft) during a 100-year flood event. This is a slight decrease compared to the initial 1.56 cm (0.05 ft) increase in water levels immediately following project construction. Flood impacts decrease over time because increases in Steinberger Slough conveyance more than offset decreases in marshplain (i.e., floodplain) conveyance. However, even in the "worst case" with no scour along Steinberger Slough, peak flood water levels during a 100-year flood event are expected to increase by only 1.8 cm (0.06 ft).

- Managing for Uncertainties. One source of uncertainty in the above peak water level increase estimate is how closely the actual hydraulic characteristics of the flow control structures placed in Corkscrew and Smith Sloughs will match those simulated in the modeling. Flood performance will be affected if the flow control structures allow more or less flow than modeled. To address this uncertainty, USFWS will monitor the performance of and adaptively manage the flow control structures as needed. Modifications to the structures will be made if post-project measurements of tidal flows indicate that the flow control structures are not functioning per the design criteria given in the Restoration and Management Plan and incorporated into the model.

3 APPROACH AND FLOOD CRITERIA

3.1 APPROACH

PWA carried out a series of hydrodynamic model runs as part of the restoration design development that lead to the August 2002 Alternative. Flow control structures included in the revised restoration design have the effect of raising water levels along the upstream reach of Steinberger Slough during low tide, as shown in Figure 1. These changes in water levels are expected to persist until sufficient scour of Steinberger Slough occurs to fully convey the tidal prism that would otherwise pass through the over-sized Redwood Creek Shipping Channel. Modifications to the restoration design that improved the low tide drainage were not apparent without impacts to other project constraints such as increased tidal currents at Pete's Outer Harbor and increased sedimentation along lower Redwood Creek. Poor low-water drainage is often an indication of restricted channel conveyance which may affect flood flows. Therefore, PWA carried out a set of additional simulations in order to better understand the potential flood impacts associated with the August 2002 Alternative. The intent of this analysis was to quantify the potential flood impacts for preliminary assessment and to screen possible mitigation measures.

3.2 FLOOD HAZARD CRITERIA

Although the tidal hydrodynamic model runs carried out in the development of the restoration design showed changes in the average and low tide water levels along sections of Steinberger Slough, flood impacts were not immediately clear since extreme high tides are often the cause of flooding in coastal areas. Therefore, PWA revised the flood hazard criteria and carried out further analysis in order to examine the extent of project-induced changes in water levels during extreme events.

PWA adopted flood criteria used in previous studies that consisted of certain combinations of steady-state creek flows and bay tides. The two most recent flood studies of Pulgas Cordilleras Creeks are an analysis of both creeks for the Federal Emergency Management Agency (FEMA, 1981) and a separate study of Pulgas Creek for Caltrans (Peterson 2000). Both reports are discussed in PWA 2000, along with descriptions of the existing flooding and drainage of the watershed.

Estimates of various creek flows and bay tides are listed, respectively, in Tables 1 and 2. Additional information was collected to characterize the 1.6-year creek flow for Pulgas Creek, which was found to be 755 cfs (Peterson 2000).

TABLE 1. Estimated Creek Flows

Location		**Drainage Area (sq. mi.)**	**Q_{10} (cfs)**	**Q_{30} (cfs)**	**Q_{50} (cfs)**	**Q_{100} (cfs)**	**Source**
Redwood Creek	USGS Gauge	1.82	--	720	--	--	KJC (1986)
	Broadway	8.8	1800	--	3200	3800	FEMA (1981)
	Highway 101[1]	9.3	1900	--	3300	4000	FEMA (1981)
Cordilleras Creek	El Camino Real	3.3	470	--	940	1170	FEMA (1981)
	Highway 101	3.6	525	--	700[2]	850[2]	FEMA (1981)
Pulgas Creek	Highway 101	3.6	1005	--	1460	1820	FIA (1977)[3]

Notes:
[1]KJC (1986) lists a 30-year peak flow of 1800 cfs at Veteran's Blvd just upstream of Highway 101. This flow is approximately equal to the 10-year peak flow FEMA values at Broadway and Highway 101, 1300 and 1700 feet upstream and downstream, respectively. It is likely that this discrepancy results from different methods of analysis used in the two studies.
[2]The flows at El Camino Real are higher than those downstream at Highway 101. This discrepancy is caused by a diversion of high flows from Cordilleras Creek to Pulgas Creek that FEMA factored into its analysis for the 50- and 100-year flows (E. Boscacci, pers. comm.). KJC (1986) lists a 30-year peak flow of 1000 cfs at Highway 101. This flow, which is significantly higher than the FEMA values at Highway 101, indicates that the diversion of high flows was likely not included in the KJC analysis, but the discrepancy may also be the result of different methods of analysis.
[3]The flow values were not listed in the 1977 San Carlos FIS (FIA, 1977), but were obtained from FIS back-up data. The 50- and 100-year flows include diverted flows from Cordilleras Creek (E. Boscacci, pers. comm.).

Q_N is the creek flow with a return period of N years.

TABLE 2. Estimated Bay Tides

Event	Water Surface Elevation (ft NGVD)	Agency
Highest Expected Tide	7.1	Caltrans (Peterson 2000)
Highest Annual Tide	5.1	FEMA (FEMA 1981)
Mean Sea Level	0.0	Caltrans (Peterson 2000)

4 MODEL RUNS AND RESULTS

We carried out a series of steady-state model runs to calculate water surface elevations with and without project for various combinations of tides and creek flows. Table 3 lists the complete run catalog, input conditions, and results. As noted in the table, some runs were directed at examining various mitigation measures. Consistent with the previously cited FEMA and Caltrans findings, our results indicate that flood water levels are mostly driven by the bay tides, with creek flows of secondary importance.

4.1 EFFECT OF THE PROJECT ON PEAK FLOOD WATER LEVELS

Numerical simulations using with- and without-project conditions lead to the following findings:

- In general, changes in water level were greater when FEMA criteria were applied to flood events than when Caltrans criteria were used. However, the highest absolute water surface elevations were simulated by Caltrans criteria that combined the highest expected tide with relatively low creek flows.

- Project-related changes in water levels for 10- and 50-yr events were less than those generated by 100-yr events.

- Model results indicate that water level changes due to the project under long-term conditions may be overstated unless sea level rise and scour of the sloughs are taken into account. Long-term scenarios modeled in this study accounted for changes in flood conveyance due to sedimentation on the marshplain, although sea level rise and channel scour were included in some runs.

- Various combinations of tides and creek flows were examined, and modeling indicates that high tides govern the water levels throughout the system. This is consistent with previous analysis (FEMA 1981, Peterson 2000). The highest water surface elevations were simulated under 100-yr Caltrans criteria, which included the highest expected tide (HET) as a boundary condition.

- Our analysis tested several approaches to further reducing project-related potential flood increases, such as dredging Steinberger Slough, routing some flow through the Inner Bair borrow ditch, and additional levee lowering (see Runs 8 through 13). Dredging along the length of Steinberger Slough would reduce greatly reduce flood impacts, with model results indicating only a 0.3 cm (0.01 ft or 0.12 inches) increase in water level. Adding culverts and dredging along the borrow ditch between Inner Bair and Highway 101 is not expected to significantly improve flooding, and would be complicated by the existing sewer line. Assuming levee overtopping, through levee subsidence or extensive levee lowering, long-term impacts were found to be only 0.7 cm (0.28 inches) due to the additional conveyance of the marshplain.

- Levee lowering associated with the proposed restoration actions lowers peak flood water levels, especially in the long-term, by increasing the conveyance of the marshplain.

The 100-yr flood event based on FEMA criteria consisted of 100-yr creek flows applied simultaneously with the highest annual tide (HAT). Results from applying this criteria indicate higher project-related impacts than when using Caltrans criteria. Model results from Run 5 show short-term (immediately after breaching) increases in water level of about 0.05 ft. In the long term, increased conveyance due to scouring along Steinberger Slough are partially offset by reduced conveyance through Middle and Outer Bair Island as marshplain sedimentation. Simulations indicate that under these conditions, long-term project-induced changes may increase flood water levels by 0.04 ft. Predictions of long-term flood impacts are less certain than predictions of short-term impacts because of uncertainties in future slough erosion and marshplain sedimentation. However, we estimate a "worst case" potential increase in peak flood levels of 0.06 ft for long-term conditions. This scenario assumes no scour of Steinberger Slough and full marshplain sedimentation in the restored ponds.

Project-related changes in water levels decrease with creek flow. For example, Run 4 shows that short-term increases in peak flood water levels are limited to 0.03 ft during a 10-year flood events.

4.2 MONITORING AND ADAPTIVE MANAGEMENT

One source of uncertainty in the above peak water level increase estimate is how closely the actual hydraulic characteristics of the flow control structures placed in Corkscrew and Smith Sloughs will match those simulated in the modeling. Flood performance will be affected if the flow control structures allow more or less flow than modeled. To address this uncertainty, the proposed restoration action includes performance monitoring and adaptive management of the flow control structures as needed. The monitoring plan (HTH 2003) includes measurement of tide elevations and flow velocities at Year 0, immediately after project implementation. The measurements will be used to evaluate whether the structures are functioning per the design criteria given in the Restoration and Management Plan and incorporated into the model. The USFWS will be responsible for adjustments to the structures after construction that may be needed to meet the design criteria. The structures will be designed to allow adjustments (such as the addition or removal of rip-rap, or adjustment of weir elevations) for flexibility of post-construction management. Monitoring will continue on a yearly basis through Year 3 to ensure that flood hazards decrease in time as tidal scour along Steinberger Slough increases downstream conveyance.

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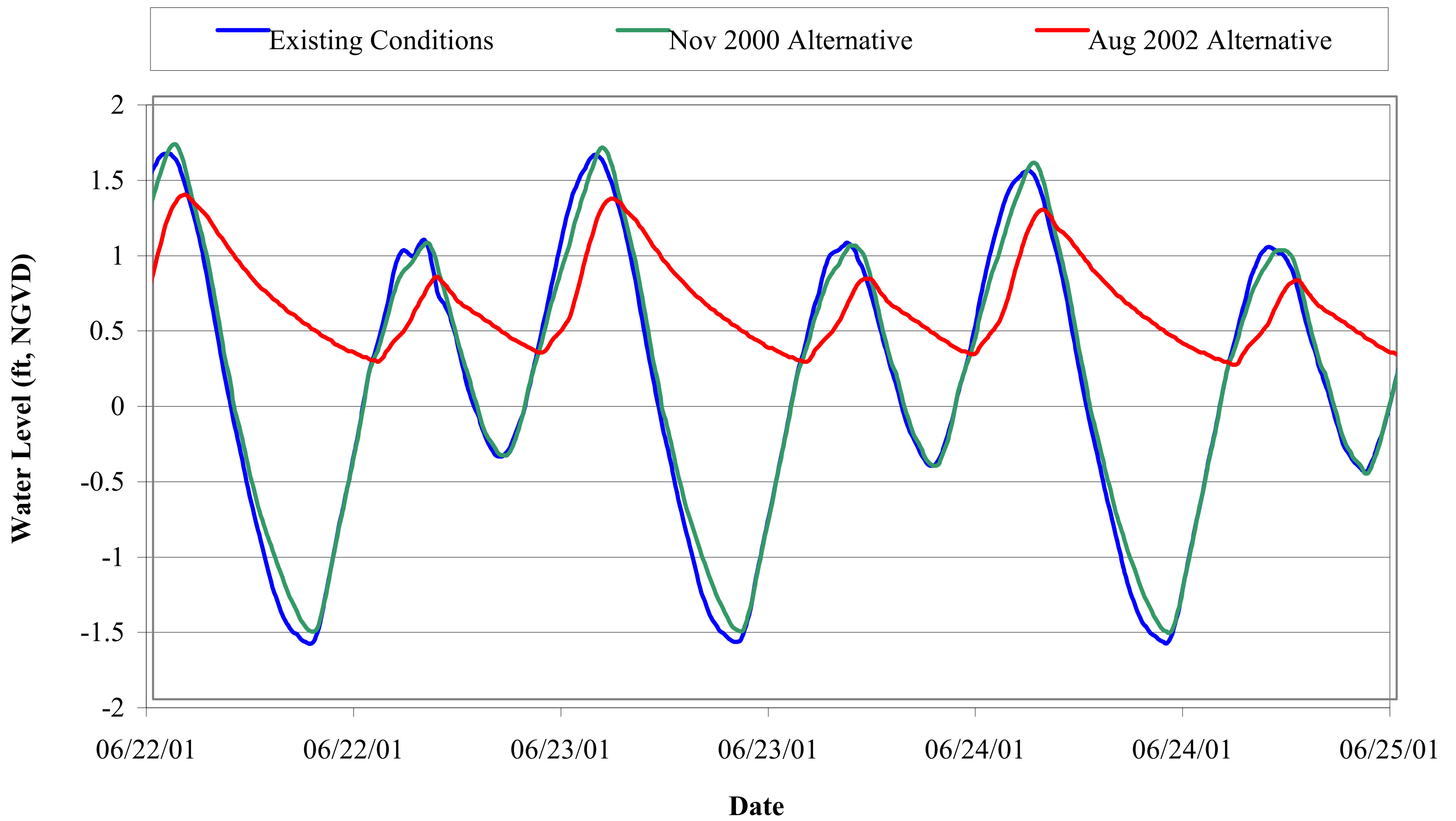
ATTACHMENTS

Figure 1. Water Levels in Steinberger Slough over Representative Tide Cycle.
Table 3. Run Catalog and Changes to Flood Water Levels.



Notes: Simulated water levels in Steinberger Slough at confluence with Smith Slough with no creek flows. In Aug 2002 Alternative, flow restrictions along Corkscrew and Smith Sloughs limit conveyence until Stienberger Slough scours adequately.

Source: Numerical simulation.

figure 1

Bair Island Restoration - Flood Analysis

Tides at Stienberger Slough - No Creek FLows

P.W.A

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Table 3. Run Catalog and Changes to Flood Water Levels at the Mouths of Pulgas and Cordilleras Creeks

Run	Project Features Modeled	Changes in Morphology Modeled	Flood Event	Design Storms: Discharge	Design Storms: Tides	Modeled Water Levels (m NGVD): Existing Conditions	Modeled Water Levels (m NGVD): Initial Conditions with Project	Modeled Water Levels (m NGVD): Long Term Conditions with Project	Difference in Water Levels: Initial Conditions with Project	Difference in Water Levels: Long Term Conditions with Project	Comments
1	Basic*	Ponds elevation at MHHW and no slough scour.	Caltrans 100-yr	Q1.6 at Pulgas Q10 at Cordilleras	HET (2.16 m NGVD)	Pulgas = 2.163 Cord. = 2.166	Pulgas = 2.166 Cord. = 2.170	Pulgas = 2.166 Cord. = 2.170	Pulgas 0.3 cm Cord. 0.4 cm	Pulgas 0.3 cm Cord. 0.4 cm	Increases over exisiting condtions is small due to high HET tide level
2	Basic	Ponds elevation at MHHW and no slough scour.	Caltrans 100-yr	Q100	MSL (0 NGVD)	Pulgas = 0.593 Cord. = 0.702	Pulgas = 0.816 Cord. = 0.887	Pulgas = 0.933 Cord. = 0.989	Pulgas 22.3 cm Cord. 18.5 cm	Pulgas 34.0 cm Cord. 28.7 cm	Increases over exisitng conditions are larger with MSL
3	Basic	Ponds elevation at MHHW and no slough scour.	FEMA 50-yr	Q50	HAT (1.555 NGVD)	Pulgas =1.557 Cord. = 1.571	Pulgas =1.569 Cord. = 1.583	Pulgas =1.579 Cord. = 1.592	Pulgas 1.2 cm Cord. 1.2 cm	Pulgas 2.2 cm Cord. 2.1 cm	Long term increases of about 2 cm (approx. 1 inch)
4	Basic	Ponds elevation at MHHW and no slough scour.	FEMA 10-yr	Q10	HAT (1.555 NGVD)	Pulgas =1.555 Cord. = 1.563	Pulgas =1.563 Cord. = 1.571	Pulgas =1.567 Cord. = 1.575	Pulgas 0.8 cm Cord. 0.8 cm	Pulgas 1.2 cm Cord. 1.2 cm	Long term increases of about 1 cm (approx 0.5 inch)
5	Basic and project-related levee lowering is included in the numerical model. This represents most likely short-term conditions, and worst long-term conditions.	Ponds elevation at MHHW and no slough scour.	FEMA 100-yr	Q100	HAT (1.555 NGVD)	Pulgas =1.561 Cord. = 1.578	Pulgas =1.576 Cord. = 1.591	Pulgas =1.579 Cord. = 1.595	Pulgas 1.5 cm Cord. 1.3 cm	Pulgas 1.8 cm Cord. 1.7 cm	Assumes levee lowering but no change in Stein Sl.
6 - no SLR	Basic	Ponds elevation at MHHW and sections of Steinberger and Corkscrew deepened based on hydraulic geometry.	FEMA 100-yr	Q100	HAT (1.555 NGVD)	Pulgas =1.561 Cord. = 1.578	n.m.	Pulgas =1.584 Cord. = 1.600	n.m.	Pulgas 2.3 cm Cord. 2.2 cm	less than 1 inch increase under long-term (assumes deeper Stein Sl.)
6 - SLR	Basic and project-related levee lowering is included in the numerical model. This represents most likely long-term conditions.	Ponds elevation at MHHW and sections of Steinberger and Corkscrew deepened based on hydraulic geometry. Assume 50 years of SLR	FEMA 100-yr	Q100	HAT + SLR (1.715 NGVD)	Pulgas =1.715 Cord. = 1.728	n.m.	Pulgas =1.727 Cord. = 1.739	n.m.	Pulgas 1.2 cm Cord. 1.1 cm	approx 0.5 inch increase under long-term (assumes deeper Stein Sl., SLR, and levee lowering)
7	Basic	Ponds elevation at MHHW. Assume levees along Steinberger Slough failed/subsided to MHW.	FEMA 100-yr	Q100	HAT (1.555 NGVD)	Pulgas =1.561 Cord. = 1.578	n.m.	Pulgas =1.568 Cord. = 1.585	n.m.	Pulgas 0.7 cm Cord. 0.7 cm	less than 1 in increase. Sheet flow over marshes add to conveyence thru Steinberger Slough
8	Basic plus levees along Steinberger Slough lowered to MHHW (MM).	n.m	FEMA 100-yr	Q100	HAT (1.555 NGVD)	Pulgas =1.561 Cord. = 1.578	Pulgas =1.562 Cord. = 1.578	n.m.	neglible impacts	n.m.	less than 1 in increase. Sheet flow over marshes add to conveyence thru Steinberger Slough
9	Basic plus dredge Steinberger Slough to -4 m NGVD (MM).	Ponds elevation at MHHW.	FEMA 100-yr	Q100	HAT (1.555 NGVD)	Pulgas =1.561 Cord. = 1.578	Pulgas =1.564 Cord. = 1.580	Pulgas =1.564 Cord. = 1.581	Pulgas 0.3 cm Cord. 0.2 cm	Pulgas 0.3 cm Cord. 0.3 cm	negligible impacts
10	Basic plus cut thru high marsh between Inner Bair and Hwy 101 (approx 650-ft long, 50-ft wide, and 0.0 ft NGVD deep) with 1 existing culvert (MM)	Ponds elevation at MHHW.	FEMA 100-yr	Q100	HAT (1.555 NGVD)	Pulgas =1.561 Cord. = 1.578	n.m.	Pulgas =1.594 Cord. = 1.609	n.m.	Pulgas 3.3 cm Cord. 3.1 cm	approx 1 inch impacts near Pulgas, less near Cordilleras
11	Basic plus cut thru high marsh between Inner Bair and Hwy 101 (approx 650-ft long, 50-ft wide, and 1.5 ft NGVD deep) with 1 existing culvert (MM).	Ponds elevation at MHHW.	FEMA 100-yr	Q100	HAT (1.555 NGVD)	Pulgas =1.561 Cord. = 1.578	n.m.	Pulgas =1.594 Cord. = 1.609	n.m.	Pulgas 3.3 cm Cord. 3.1 cm	approx 1 inch impacts near Pulgas, less near Cordilleras
12	Basinc plus cut thru high marsh between Inner Bair and Hwy 101 (approx 650-ft long, 50-ft wide, and 0.5 m NGVD deep) with 2 culverts (MM).	Ponds elevation at MHHW.	FEMA 100-yr	Q100	HAT (1.555 NGVD)	Pulgas =1.561 Cord. = 1.578	n.m.	Pulgas = 1.592 Cord. = 1.606	n.m.	Pulgas 3.1 cm Cord. 2.8 cm	approx 1 inch impacts near Pulgas, less near Cordilleras
13	Basic plus cut thru high marsh between Inner Bair and Hwy 101 (approx 650-ft long, 50-ft wide, and 1.5 m NGVD deep) with 10 culverts (MM).	Ponds elevation at MHHW.	FEMA 100-yr	Q100	HAT (1.555 NGVD)	Pulgas =1.561 Cord. = 1.578	n.m.	Pulgas = 1.590 Cord. = 1.584	n.m.	Pulgas 2.9 cm Cord. 0.6 cm	< 1 inch impacts near Pulgas, less near Cordilleras

NOTES: n.m. = not modeled
HET = highest expected tide
HAT = highest annual tide
MSL = mean sea level
SLR = sea level rise
Basic = channel alignment and breaches from Aug 2002 Alternative but NOT levee lowering. All with-project runs include flow control structures in Smith and Corkscrew Sloughs and levee breaches per R&M Plan (HTH and PWA 2002).
MM = mitigation measure. Applied to Runs 8 - 13.

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ECOLOGICAL CONSULTANTS