# SOUTH BAY GEOMORPHIC ASSESSMENT

# South Bay
# Geomorphic Assessment

Submitted to:
California State Coastal Conservancy
U.S. Fish & Wildlife Service
California Department of Fish and Game

Prepared by:
Philip Williams & Associates, Ltd.

August 2006
Revised October 2006

<This page intentionally left blank>

## TABLE OF CONTENTS

**FIGURES**

## TABLES

## APPENDICES

# ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| Bay | San Francisco Bay |
| Central Bay | Central San Francisco Bay |
| cfs | cubic feet per second |
| DTM | digital terrain model |
| far South Bay | portion of the South Bay south of the Dumbarton Bridge |
| IPCC | Intergovernmental Panel on Climate Change |
| km | kilometer |
| l | liter |
| LiDAR | Light Detection and Ranging |
| m | meter |
| mg | milligrams |
| MHHW | mean higher high water |
| MLLW | mean lower low water |
| mm | millimeter |
| $Mm^3$ | million cubic meters |
| Mt | million tonnes |
| NAVD | North American Vertical Datum of 1988 |
| NOAA | National Oceanic and Atmospheric Administration |
| ppm | parts per million |
| s | second |
| SBSP | South Bay Salt Pond |
| SFEI | San Francisco Estuary Institute |
| South Bay | South San Francisco Bay |
| SSC | Suspended sediment concentration |
| $tm^{-3}$ | tonnes per cubic meter |
| USGS | U.S. Geological Survey |
| yr | year |

# 1. INTRODUCTION

The South Bay Salt Ponds (SBSP) Restoration Project constitutes a major change in the estuarine landscape of the South Bay. This landscape of marshes, mudflats and open water has evolved and changed over the last few thousand years by the interaction of sediments, tidal currents and waves with rising sea-level (Atwater 1979; Atwater and others 1977). With no tidal restoration, the geomorphology, or shape of the estuary, that dictates the extent and mix of physical habitats, will continue to change in response to long-term erosional and depositional processes. With large-scale tidal restoration, alterations in the sediment dynamics within the estuary are expected that will affect this mix of habitats and the ecologic functions dependent on them. This is because the ponds are former tidal marshes that were diked and then subsided. Restoring these ponds to vegetation colonization elevations requires taking advantage of the natural deposition of estuarine sediments brought into the restored site on flood tides. This new sediment demand or "sink" will affect Bay bathymetry and the extent of offshore mudflats and marshes over the long-term in the South Bay. In addition, the availability of estuarine sediment within the whole of the South Bay determines how quickly, or whether tidally restored ponds can convert, to saltmarsh.

This report documents a simple geomorphic analysis intended to provide an overview of the potential magnitude of these landscape-scale geomorphic impacts and the extent of mudflat and marsh anticipated in the whole South Bay landscape, 50 years in the future, for the three alternatives identified in the restoration project.  This analysis can be used to assess ecologic implications of physical habitat change, such as the impact of mudflat area change on shorebird feeding.  It also informs an adaptive management process that is an integral part of the restoration project, whose purpose is to anticipate, guide, and mitigate those impacts through a better understanding of how and why the estuary is responding to natural and human induced changes.

This report also addresses key questions outlined by the SBSP Science Team in its *Draft Science Synthesis Review of Sediment Management Issues* (Schoellhamer and others 2005) and supplements the SBSP *Hydrodynamics and Sediment Dynamics Existing Conditions Report* of March 2005.

This analysis draws upon the historical bathymetric change data and analysis carried out by the United States Geological Survey (USGS), a cooperating agency with the Coastal Conservancy on South Bay studies (Foxgrover and others 2004;Jaffe and Foxgrover 2006a;Jaffe and Foxgrover 2006b) .

<This page intentionally left blank>

## 2. CONCLUSIONS

1. Restoration of the South Bay ponds to tidal marsh relies on the process of natural estuarine sedimentation to rebuild these subsided former saltmarshes back to self-sustaining marsh plain elevations. Over the 50-year restoration period this will create a sediment demand or “sink” within the South Bay estuarine system of between 20 and 50 million tonnes, with about 80% of this demand created by more deeply subsided ponds in the upstream reach of the estuary in the far South Bay.
2. Estuarine sediments the South Bay are mainly derived from wave erosion of the extensive shallows and mudflats north of Dumbarton Bridge, supplemented by inflow of sediment from the Central Bay, flood borne sediments from local watersheds, and the erosion of fringing marshes. These sediments are conveyed by wind-driven currents into the upstream reach of the estuary causing increased suspended sediment concentrations and rapid shoaling in this area.
3. Estimates of the total available sediment supply from these sources, over the 50-year restoration period is estimated to range from approximately 40 to 100 million tonnes. The sediment demand of restored ponds constitutes a large proportion of the sediment supply and will alter the evolution of the South Bay morphology and the South Bay’s sediment dynamics.
4. The area north of the Dumbarton Bridge, where offshore mudflats have been eroding, currently provides about 25 $km^2$ or half of the total mudflat habitat of the South Bay. Here erosion rates are expected to be largely unaffected by restoration actions, but to increase due to accelerated sea-level rise resulting in a loss of 15 $km^2$ or 60% over the next 50 years.
5. In far South Bay, where offshore mudflats have historically been expanding, sediment demand created by restoration actions is expected to slow or reverse this expansion, causing a reduction in mudflat area relative to “no action.”
6. In the analysis of changes in mudflat area it is assumed that pond breaching will occur in phases over the 50-year implementation period. Initially, 10% of the project area is restored at Year Zero. A further 20% is restored at Year 10, making a total of 30% of the ponds restored. This approximates to Alternative A, “no action” alternative as identified in the restoration project. Another 20% of the project area is restored at Year 20 which is Alternative B (making 50% restored), followed by 20% more at year 30, and 20% more at Year 40 (making it 90% restored - Alternative C).
7. In the far South Bay it is predicted that no action (Alternative A) would result in a gain of about 2 $km^2$ of mudflat over the next 50 years. Compared to the no action alternative, tidal restoration under Alternative B is predicted to result in the loss of about 2 $km^2$ of mudflats while Alternative C is predicted to result in the loss of about 10 $km^2$ of mudflats. When compared to the current extent of mudflats in this area in 2005 (instead of the predicted extent of mudflats in 50 years under no action), Alternatives B and C are predicted to result in no loss and an 8 $km^2$ loss of mudflats, respectively.
8. The net effect of predicted mudflat changes for the entire South Bay over the 50-year implementation period is summarized in the table below. With no action (Alternative A) we estimate that the South Bay will lose approximately 14 $km^2$ or 28% of its existing offshore mudflats. With implementation

of the restoration project (Alternatives B and C) a further loss of mudflats of up to 10 km $^2$ could occur, resulting in a total reduction of up to 50% of existing offshore mudflat extent.

**Table 2-1. Net Mudflat Changes Over the Next 50 Years**

| Year | Mudflat Area km$^2$ |
|---|---|
| 2005 | 50 |
| 2056 Alt A. | 36 |
| 2056 Alt B. | 34 |
| 2056 Alt C | 26 |

9. We expect estuarine sediment supply and sedimentation rates to be sufficient to allow vegetation colonization in all restored ponds within the 50-year planning horizon, provided the intensity of wind-wave action is limited.
10. With all alternatives, including no action, an increase in tidal marsh within the South Bay is expected. Under no action (Alternative A), an increase of 19 km$^2$ or 45% of current area is predicted. Alternatives B and C would result in an additional increase of 11 km$^2$ and 28 km$^2$, respectively. Alternative C is predicted to result in a total of 89 km$^2$ of tidal marsh in the South Bay, a 110% increase compared to the area of tidal marsh (42 km$^2$) that exists today.

**Table 2-2. Tidal Marsh Changes Over the Next 50 Years**

| Year | Tidal Marsh Area km$^2$ |
|---|---|
| 2005 | 42 |
| 2056 Alt A. | 61 |
| 2056 Alt B. | 72 |
| 2056 Alt C | 89 |

11. Erosion of offshore mudflats is expected to cause accelerated erosion of Bay-edge marshes and levees. However, this process has not been quantified.
12. There is uncertainty in the estimate of the long-term sediment budget components that support this analysis. The most significant uncertainties are:
    a. Future rates of relative sea-level rise
    b. Characterization of the sediment dynamics, sediment transport pathways, and deposition patterns within the South Bay.
    c. Hydrodynamic changes in tidal range.
13. A sensitivity analysis for Alternative C that tested a range of these uncertainties indicates that under the hypothetical “best case” scenario there could be a small increase in mudflats in the far South Bay (south of Dumbarton Bridge) but still a significant loss of mudflats to the north of Dumbarton Bridge; under the

"worst case" there would be major loss of mudflats in the far South Bay and also north of Dumbarton Bridge.

14. This geomorphic assessment has been carried out in isolation from any hydrodynamic modeling results. Uncertainties in these projections can be reduced with long-term monitoring and implementation of applied studies, including a more sophisticated analysis of sediment dynamics that links hydrodynamic modeling of sediment transport pathways and wind-wave effects to the sediment budget analysis presented here.
15. The adaptive management program incorporated in the restoration project allows opportunities for anticipating, minimizing, or mitigating these landscape-level geomorphic impacts. Potential adaptive management measures include: phasing of tidal restoration of individual ponds to match availability of sediment, removal of bayfront levees to restore mudflats instead of tidal marshes, and the re-creation of erodible marsh edge shorelines to convert saltmarsh to mudflat.

<This page intentionally left blank>

# 3. CONCEPTUAL MODEL OF THE GEOMORPHIC EVOLUTION OF SOUTH BAY HABITATS

## 3.1 Estuarine Context

San Francisco Bay's intertidal habitats are integral components of a dynamic evolving estuarine system that is itself, a single coherent landform. The estuary evolves as its smaller geomorphic constituents respond to changing environmental conditions, such as long-term sediment supply and relative sea-level rise. Deep subtidal channels, shallow subtidal bays, intertidal mudflats, and tidal saltmarsh that form on the estuarine margin are all components of the estuary that interact and evolve with each other in response to physical processes. The form of the estuary and its intertidal wetlands at any given time is the current expression or "snapshot" of the interaction and evolution of hydrodynamic and geomorphic processes within the estuary.

Estuaries alter their form mainly by the erosion and deposition of sediment, either sediment that is reworked from other parts of the estuary, or that enters the estuary from local watersheds (Pethick 1984; Woodroffe 2002). Sediment circulates and moves between each of the components within the estuary, allowing the estuary as a whole to continually adjust towards an equilibrium form in response to changes in hydrodynamic or geomorphic processes (Allen 1990; Long 2000; Pethick 1996).

With rising relative sea-level the estuary "transgresses" inland and increasing water depths and wind fetches allow waves to erode the shallow subtidal and intertidal estuarine margin and redistribute eroded sediment both inshore to support high intertidal marshes, and offshore to more quiescent deepwater areas (Reed 1990). And so, with rising relative sea-level the estuary is always evolving and redistributing sediment, yet maintaining an overall mosaic of habitats (Pethick and Crooks 2000; Shennan 2003). The extent and structure of these habitats is also influenced by other physical processes that determine the distribution of sediments between the geomorphic components of the estuary: the tidal range, the wind-wave climate, flood flows delivering sediment, tidal circulation, and the presence of sediment sinks within the system (Anthony and Orford 2002; Cooper 2002). Human activities can alter all of these processes and so influence the shape of the evolving estuary (Pethick 2001).

## 3.2 The Evolution of the South Bay

The South Bay (here defined as the area south of the South Bay Habitat Boundary defined by SFEI) is geomorphically a self-contained system whose sediments have been derived mainly from local watersheds (Watson 2004). Its sediment supply might also have been supplemented by infrequent large winter flood events on the Sacramento River that can intrude sediment-laden water into the South Bay.

The intertidal wetland habitats of the South Bay evolved over the last 4000 years, as gradually rising relative sea-level inundated the gently sloping margins of the Bay (Figure 1). Tidal marshes kept pace with rising relative sea-level by sedimentation and the accumulation of organic material such as peat within marsh soils at about the elevation of the mean higher high water (MHHW) (Atwater and others

1979; Watson 2004). As relative sea-level rose, at a rate of about 1 to 2 $mmyr^{-1}$ (millimeters per year) tidal marshes migrated inland, creating extensive vegetated marsh plains drained by a complex network of large sinuous tidal channels. Each tidal channel has a tidal "watershed," the marsh area that each channel fills and drains, and their scale dictates the size and density of the tidal channel system formed in equilibrium with the tidal prism of upstream marshes (Orr and others 2003; Pestrong 1965). These watersheds are distinguished by very subtle changes in elevation, and in the ancient marshes of San Francisco Bay marsh plain ponds can occur at the watershed divide (Collins and Grossinger 2004). They receive tidal inflow only on the highest tides and can become hypersaline in the summer. At the inland edge of the transgressing marsh seasonal salt pans also form where tidal drainage is least effective.

With adjustment of the estuary to rising sea-level, both marshes and mudflats moved inland. Strong wind-wave action gradually eroded the bayfront marsh edge eventually forming the extensive shallows and mudflat margin of the South Bay, while the landward edge of the marsh advanced inland. The slope of this erosional platform maintains an equilibrium form with the long-term wave climate, sediment supply, and sea-level rise (Friedrichs and Aubrey 1996; Pritchard and Hogg 2003; Pritchard and others 2002; Roberts and others 2000). Because this erosional platform consists of cohesive sediments of the buried ancient marsh, it is highly consolidated, and in the more wave-exposed areas can be covered by a veneer of sand and shell.

Wave action was strongest, and hence shallows most extensive, on the eastern shore. Here wave action was sufficient to deposit ridges of sand, shell, and wrack that blocked small tidal channels creating extensive natural salt flats.

As the South Bay evolved over time scales of centuries the area of intertidal wetland habitats changed. With gradually rising sea-level the area of subtidal habitats increased, the area of wave-dominated mudflats expanded with increasing wave fetch, and the area of tidal marsh expanded or contracted depending on fluctuations in sediment supply and whether the rate of inland migration was greater or less than the rate of marsh edge erosion induced by relative sea-level rise (Atwater and others 1979). As sea-level rose, the estuary expanded and the main subtidal channel was "drowned," creating an internal sediment sink that captured a portion of the sediment recirculating within the estuary.

### 3.3 Human Interventions in the South Bay

European-American colonization over the last 200 years has transformed not only the landscape of the estuary, by diking, filling, and groundwater pumping, it has also changed the processes that sustain wetland habitats of the estuary by altering the sediment budget (interactions between sources and sinks), hydrodynamics, and salinity distribution.

Sediment supply to the South Bay, both from local watersheds and possibly the Sacramento River, changed significantly over the last 200 years. With 19th century grazing, agriculture, and logging it is likely that sediment delivery from local watersheds increased significantly. In addition many local creeks that formally dissipated floodflows and sediment at the Bay margin were channelized directly to the Bay

(Collins and Grossinger 2004). Later, dams on the major local streams reduced sediment inflow (Wright and Schoellhamer 2004).

Hydraulic mining and watershed disturbance in the Sierra in the 19th century substantially increased sediment delivery and the frequency of flood pulses to the North and Central Bay (Gilbert 1917). However, it is still not clear how much of this sediment reached the South Bay. Over the last 50 years sediment delivery from the Central Valley has substantially decreased due to reservoir construction, recovering watersheds, reduction of flood peaks, and diminishment of the hydraulic mining pulse.

Over the last 60 to 150 years most of the South Bay's tidal marshes were diked off for salt pond production. This obliterated vegetated tidal marsh functions and associated habitats, specifically marsh plain ponds, perimeter salt pans, transitional marshes, and the large tidal channels within the marsh. Diking of the marshes also affected estuarine processes. The tidal prism was reduced, allowing tidal sloughs to silt in and narrow as fringing marsh between the levees expanded. It appears that this process is still affecting Coyote Creek, where the channel is narrowing and fringing marshes expanding. Rip-rapped levees on the salt ponds precluded the opportunity for eroding mudflats to migrate inland. Diking of the marshes eliminated a sediment sink allowing more sediment to be recirculated within the estuary, probably resulting in increased suspended sediment concentrations (SSCs) and higher rates of siltation in the subtidal channel.

Within the far South Bay (the part of the South Bay to the south of Dumbarton Bridge), land subsidence occurred due to groundwater pumping in the mid-20th century (Poland and Ireland 1988). During this period, sedimentation overall has kept pace with subsidence (Foxgrover and others 2004) and, based on their hypsometry, the mudflats appear to be reaching equilibrium with the local wind-wave climate. Most significantly, the degree of subsidence in the salt ponds on former marsh plains has created a large new potential sediment sink within the system that can affect the sediment dynamics and sediment budget of the South Bay when tidal action is restored.

The sediment budget of the South Bay has also been altered by dredging to maintain flood control channels, navigation, and to provide construction materials. Since the 1970's, a series of restoration projects have created new sediment sinks at the Bay margin.

## 3.4 Conceptual Model of Sediment Dynamics of the South Bay

Although the South Bay receives inputs of sediment from local watersheds and from the Central Bay, the major source of sediment in circulation within the South Bay is the wave-induced erosion of consolidated mud on the surface of the shallows and mudflats (collectively referred to as the "sweep zone") on the east and west side of the deep subtidal channel north of the Dumbarton Bridge (Foxgrover and others 2004).

Once eroded, this mud becomes mobile and though it is continuously re-eroded and deposited, it does not replenish the erosional platform because of its low settling velocity. Instead, much of this eroded sediment stays in motion and migrates southwards with the prevailing wind. SSC is highly correlated with wind speed; during periods of high summer northwesterly winds SSCs increase and this sediment moves south with the wind-driven circulation through the Dumbarton Narrows from where it can be dispersed into the far South Bay on flood tides.  A portion of this eroded sediment circulates into the subtidal channel, where it is either deposited or moves north out of the South Bay into the Central Bay (Schoellhamer 1996).  On the west side of the South Bay, southward movement of sediment is partially interrupted by the actively dredged Redwood City Harbor channel.  Figure 2 illustrates the typical pathways for the movement of sediment within the South Bay in response to wind-driven residual currents describing our conceptual model of sediment transport.

The resuspension of eroded sediment and the movement of sediment southwards cause average SSCs to increase to the south. In the far South Bay, the eroded estuarine sediments are mixed with sediments derived from the local watershed.  Increasing sediment concentrations means that rapid sedimentation can occur if the mudflats and channels south of the Dumbarton Bridge are not in equilibrium with the wave climate and tidal flows.  It also means that as the shallows and mudflats in the far South Bay approach equilibrium with the wave climate and tidal flows the excess sediment will migrate northwards along the deeper subtidal channel.

The sweep zone shallows and mudflats in the far South Bay have been historically net depositional (Foxgrover and others 2004).  Because freshly deposited sediment has lower bulk density than old consolidated mud, the surface layers of the mudflats are continually being eroded and deposited in response to variation in wind and tidal conditions, and continually being recirculated into the water column as suspended sediment.  A portion of these suspended sediments can be captured in adjacent sediment sinks, such as restored ponds or in the subtidal channel.

The sediment dynamics within the South Bay are further described in the *Hydrodynamics and Sediment Dynamics Existing Conditions Report* (PWA and others 2005).

### 3.5 Conceptual Model of the Evolution of Restored Tidal Wetlands

When tidal action is restored to a subsided pond site through a deliberate or accidental levee breach, physical processes are set in motion that dictate the rate and manner in which the site will evolve. These sedimentary processes have been described in conceptual models of youthful saltmarsh development (Allen 1990; Orr and others 2003) and are different from the processes, dominated by sea-level rise, which created the extensive transgressive ancient marshes of the South Bay.

In a restoring marsh, flood tides carry in suspended estuarine sediments that deposit in the wave-protected slack waters of the flooded site. Ebb tidal currents are insufficient to resuspend deposited muds, except in the locations of nascent tidal channels. As sediment accumulates, large areas of intertidal mudflats form. As they rise in elevation, the period of tidal-water inundation decreases and rate of sedimentation declines.

Once tidal mudflats reach a high enough elevation relative to the tidal frame, pioneer plant colonization can occur. Initial establishment usually occurs by seed or from plant fragments. Colonization becomes progressively more rapid through lateral vegetative expansion from the pioneer plants and continued deposition of seeds and plant fragments. Figure 3 illustrates how the elevation of restored subsided sites, sheltered from significant wind-wave action, evolve in response to estuarine sedimentation processes, from subtidal, to intertidal mudflat, to initial mudflat colonization by salt-tolerant marsh plants, to ultimately a fully mature vegetated marsh plain. Sites that have relatively high initial elevations will therefore reach colonization elevation more quickly than more deeply subsided sites.

In San Francisco Bay, Pacific cordgrass (*Spartina foliosa*) is typically the first vegetation to colonize an accreting mudflat and dominates the low marsh. In the fresher parts of the Bay bulrushes (*Scirpus robustus*) will be the pioneer vegetation and will colonize lower in the tidal frame. Once mudflat colonization occurs, a vegetated marsh plain forms through lateral expansion of roots and rhizomes from established plants on the mudflat, and from plants along the site perimeter. The presence of vegetation contributes to the slow build-up of the marsh plain through sediment trapping and organic accumulation (Eisma and Dijkema 1997). Once vegetation is established, organic material will accumulate within the marsh both above ground as surface litter and below ground, through the decay of roots, rhizomes, and tubers, in the form of peat. As the vegetated marsh plain rises within the tidal frame, estuarine sediment accretion slows exponentially until a marsh plain forms at an elevation around MHHW (Atwater and others 1979). As tidal inundation decreases, soil salinities increase and pickleweed (*Salicornia virginica*) out competes cordgrass to form the characteristic saltmarsh plains of San Francisco Bay.

The rate at which the mudflat and marsh plain builds up is dependent on the amount of sediment, or SSC, carried into the site by the flood tide, the rate of relative sea-level rise, the tidal range, and the amount of wind-wave action that erodes deposited sediments. The higher the average SSC in the flood tide entering the site, the quicker the restored site will evolve. Long-term average annual SSCs at any point in the South Bay vary depending on position relative to the hydrodynamics of the estuary, in particular its proximity to extensive intertidal mudflats where sediment can be resuspended by wave action (Schoellhamer 1996). Average SSCs are ultimately determined by the long-term sediment budget of the estuary, which dictates how much sediment is available to the estuary, and the estuarine hydrodynamics that determine how it moves and where it is concentrated.

Large-scale restoration itself can affect the sediment budget and estuarine hydrodynamics. Restoring tidal action to subsided ponds creates a sediment sink within the estuary that is large enough to affect the sediment budget and decrease SSCs by capturing sediment suspended in the water column of flood tide flows entering the restored sites. This in turn can lower the rate of marsh evolution within the South Bay and accelerate the rate of mudflat erosion outside the restored ponds.

Relative sea-level rise is the product of global eustatic sea-level rise and local long-term subsidence. Due to global warming eustatic sea-level rise is predicted to accelerate. The higher the rate of sea-level rise the longer it takes for the marsh to evolve in a restoring site (Orr and others 2003).

Where restoration sites are fully tidal, periods of inundation are unrestricted and similar to those in mature marshes. Where tides are muted or restricted by narrow channels, periods of inundation are altered and vegetation establishment can be delayed. Over time, scouring action tends to enlarge constricted tidal channels, eventually restoring full tidal exchange (PWA 2004). Until this occurs, the volume of sediment entering the site on the flood tide will be reduced proportionally to the reduction in tidal prism, extending the time of evolution.

Even where the bayfront levees remain intact at a restored site, locally generated wind waves within the restored area can inhibit deposition of suspended sediment from the water column and resuspend deposited mud. In the South Bay, Schoellhamer (1996) found that SSCs were well-correlated with seasonal variations in wind shear stress. Wind-wave action can reduce the net accretion rate or “trap efficiency” in a restored site, slowing the evolution of the marsh plain and can even limit the equilibrium elevation of the site, resulting in a permanent mudflat too low to be colonized by emergent vegetation. Figure 4 illustrates the effect of wind waves in retarding evolution.

Concurrently with the physical evolution of the marsh plain, the tidal drainage system starts to form. As mudflats accrete, tidal channels first form in the mudflat. As vegetation becomes established, these sinuous mudflat channels become imprinted in the marsh plain, eventually forming a dendritic tidal channel system. Within this system, the tidal prism of the marsh “watershed” upstream mainly dictates the size and shape of the tidal channel geometry at any given point (Williams and Faber 2001). Within a mature marsh, the channel banks and the bed of lower-order tidal channels provide sustainable intertidal bare mud habitat.

## 3.6 Conceptual Model of the Evolution of Offshore Mudflats and Fringing Marshes

The shape and extent of estuarine mudflats is dominated by the prevailing wind-wave climate and sedimentary regime (Dyer 1998). Mudflats comprise the upper, intertidal portion of the wave sweep zone. This zone is defined by the vertical and lateral extent of subtidal shallows and intertidal mudflats that dissipate wave energy on the marsh edge shoreline. The lower limit of the sweep zone is defined by joint probability and scouring effect of large wind waves occurring at low tide and its shape equilibrates with the cumulative erosive effects of wind waves occurring at different tide levels.

As relative sea level rises, the sweep zone shape equilibrates and maintains its form, assuming there are no significant changes in either wave climate or sediment supply, by eroding the fringing marsh edge as illustrated in Figure 5. The rate of erosion of the marsh edge is determined by the equilibrium slope and shape of the offshore mudflat and rate of relative sea-level rise. Sediment eroded from the marsh edge is then redistributed within the estuary.

The erosional mechanism on consolidated erosional platforms, such as occur north of Dumbarton Bridge, are complex, relying on bioturbation and deflocculation as well as wave-induced bed shear stresses (Dyer 1998). Once set in motion, freshly eroded mud has a significantly lower bulk density and is more easily eroded than the underlying material, and while it can be temporarily redeposited locally, tends to be preferentially eroded and dispersed within the estuary. This means that continuous erosion occurs over long periods of time, with lateral shoreline erosion rates keeping in step with the rate of mudflat lowering. Eroded sediments can be captured in adjacent sediment sinks like deep channels or marshes, but increasing the size of these sinks and rate of capture has little effect on erosion rates of these consolidated platforms.

However, on wave-exposed depositional mudflats, such as occur in the far South Bay, mudflat accretion and erosion are more dynamic and responsive to seasonal changes in wave climate. This means that the upper layers of sediment have lower bulk densities and lower resistance to erosion and can be recirculated within the estuarine system more readily. Eroded sediments can be captured in nearby sediment sinks, like restored ponds, and are no longer redeposited within the sweep zone, resulting in mudflat lowering.

Where SSCs are high, the mudflat slope can assume a flatter or even convex shape (Kirby 2000; Roberts and others 2000). Under these conditions, it is possible for mudflats to be accreting in wave-exposed areas while the shoreline is eroding. Where the shoreline is sheltered from wave action accreting mudflats allow for expansion of fringing marsh. The shape of the offshore mudflat can influence habitat quality for shorebirds, with a convex mudflat slope providing proportionally greater exposure over a tidal cycle than a concave one.

Wherever the shoreline edge is armored with rock, shoreline erosion is halted, compressing the sweep zone as relative sea level rises. As the sweep zone becomes narrower and deeper, less sediment is supplied to the estuary; in addition marsh edge erosion no longer supplies sediment to the estuary.

## 3.7 Conceptual Model of the Evolution of Tidal and Subtidal Channels

In mesotidal estuaries like San Francisco Bay, the depth, width and cross-sectional area of tidal channels within marshes tends to equilibrate to the upstream tidal prism (Allen 2000; D'Alpaos and others 2005; Lawrence and others 2004). This means that restoring tidal action to subsided ponds can significantly increase tidal prism and create potential for scouring downstream tidal channels. Over time, the increased tidal prism will diminish as sediment builds up in the restoring site, although the net result will still be an increase in channel size. The adjustment of the tidal channel can be lagged with the increase in tidal prism by several decades (PWA 2004).

Similarly, in many estuaries the subtidal channel will also tend to equilibrate to upstream tidal prism (Pethick and Lowe 1999). Figure 6 illustrates this relationship. In those estuaries where the tidal prism is significantly reduced by diking, or where sea-level rise dominates over sedimentation processes, the subtidal channel can become oversized, acting as an internal sediment sink.

<This page intentionally left blank>

# 4. HISTORIC CHANGES IN MORPHOLOGY

## 4.1 Changes in Bathymetry and Habitat Area

USGS (Foxgrover and others 2004) and SFEI (San Francisco Estuary Institute 1998) have conducted extensive analyses of historic bathymetric and intertidal habitat changes in the South Bay. Figure 7 illustrates the following long-term changes between 1858 and 1983:

1. Diking of extensive areas of tidal marsh for salt ponds and development.
2. Retreat of the shoreline and erosion of mudflat deposits on both east and west shores of the estuary north of Dumbarton Bridge (within the sweep zone).
3. Accretion of mudflats in far South Bay.
4. Sedimentation of channel systems along the margins of the Bay (e.g. Alviso Slough, Guadalupe Slough, Coyote Hills Slough, Steinberger Slough etc.).
5. Sedimentation in the main deep subtidal channel south of Redwood City Harbor channel.

Over the past 150 years, the wide shallow subtidal and intertidal flats along the east shore of the South Bay have eroded, feeding sediment to depositional areas elsewhere across the estuary. These long-term erosional patterns can be seen by the migration inland of the -6 ft and 0 MLLW bathymetric contours progressively reducing the area of mudflats and eroding the marsh shoreline. For example, between the San Mateo Bridge and Dumbarton Bridge the landward movement of MLLW has been approximately 650 meters since 1858 (Figure 8).

In the far South Bay, the channels and shallows have been relatively stable or depositional, but over the last 50 years have infilled with sediment possibly in response to the major reduction in tidal prism due to salt pond creation in the early to mid-20th century. While the average mudflat elevation has risen, net marsh expansion has been limited and occurred in those areas sheltered from wave action such as along Coyote Creek.

The long-term changes in total mudflat and marsh area analyzed by USGS are shown in Figure 9. These plots show the net effect of mudflat loss north of Dumbarton Bridge and mudflat accretion in the far South Bay. The drastic reduction in tidal marsh area was also significantly reduced or eliminated associated habitats such as transitional wetlands, chenier ridges, beaches, marsh ponds and pans, and tidal slough systems. In particular, the higher-order deep-marsh tidal channels have been practically eliminated.

USGS (Jaffe and Foxgrover 2006a; Jaffe and Foxgrover 2006b) has analyzed bathymetric changes for different geomorphic units within the South Bay as shown in Figure 10, between two periods: 1956 to 1983 and 1983 to 2005. Figure 11 and Appendix A show average rates of erosion and accretion in the South Bay sweep zone south of the Redwood City Harbor channel and San Leandro Marina channel in these two periods. It can be seen that the same long-term evolutionary patterns have continued over the last 49 years: erosion of the sweep zone north of Dumbarton Bridge and deposition in the shallows south of Dumbarton Bridge and the subtidal channel.

Further analysis of the bathymetric changes in the far South Bay, as reflected in the estuarine hypsometry, shows that within the sweep zone, most of the sediment accumulation is occurring in the subtidal channel margin and deeper part of the shallows while the intertidal mudflats are stabilizing (Figure 12).

# 5. METHODOLOGY FOR ANALYZING MORPHOLOGIC CHANGE

## 5.1 Overview

The intent of this analysis is to estimate and compare the potential scale of impacts on intertidal habitats between "no action" and restoration alternatives for the project, and predict the likely extent of intertidal habitats 50 years into the future. This analysis also addresses the adequacy of the estuarine sediment supply to deposit enough sediment in subsided restored ponds to allow vegetation to colonize and form saltmarshes.

The methodology is based on a projection of the sediment budget of the South Bay over the next 50 years that takes into account physical constraints on erosion, sedimentation and sediment transport pathways within the estuary. It does this by analyzing the response of the major geomorphic units that comprise the estuary to waves, tidal currents, and relative sea-level rise. The major geomorphic units within the South Bay are described in more detail below and consist of channels, the wave influenced "sweep zone" (that includes mudflats and shallows), tidal marsh, and restored ponds.

## 5.2 Spatial and Temporal Boundaries

The spatial boundary for the morphologic change analysis is shown in Figure 13**.** It is defined horizontally as the area inshore of the 2005 2 m (6 ft) below MLLW contour, south of the San Leandro Marina channel on the east side of the Bay, and on the west side of the Bay, the sweep zone south of the Redwood City Harbor channel. It includes the main subtidal channel south of Redwood City Harbor channel. These boundaries were chosen to coincide with areas used by USGS in its historic analysis of bathymetric change (Foxgrover and others 2004), and contain almost all of the extensive sweep zone mudflats and shallows south of the San Bruno Shoal likely to provide sources of sediment to restored ponds and mudflats in the far South Bay. It excludes deeper subtidal areas where dredging for sand and shells has been carried out and is consistent with our conceptual model of how sediment moves in the South Bay (Figure 2). The shaded areas shown in Figure 11 show the geomorphic units analyzed by USGS that are included in the sediment budget boundary.

For each restoration alternative, the restored areas are added as sediment sinks outside the boundary. The relevant area of tidal marsh created, based on the amount of projected sediment accretion, is calculated separately. In addition, conversion of fringing marsh to mudflat due to erosion, and mudflat to fringing marsh due to sediment accretion, are calculated separately.

The vertical boundary is the MHHW tidal reference plane. Because of relative sea-level rise, this plane increases in elevation over the planning horizon creating additional volume or "accommodation space" within the estuary.

The temporal boundary or planning horizon is 50 years from baseline conditions in 2006. For convenience the 2005 mapping of the South Bay is used as representative of 2006 conditions. The 50-

year projection is a snapshot of conditions in 2056. It is recognized that the estuarine morphology continues to evolve beyond this planning horizon.

## 5.3 Sediment Budget

A sediment budget is an accounting of the sediment fluxes through a fixed boundary in space and time to estimate the net accumulation or loss of sediment within the boundary. The basic accounting unit is sediment weight, because for cohesive sediment the bulk density varies with time and loading. The accounting of sediment weight is translated to volumetric change using assumptions of bulk density described below.

A sediment budget is expressed as:

Inputs – Outputs = Change in Storage

For the South Bay the sediment budget can be expressed as:

$$\left[W_r + W_{ei} + \rho_{B1} V_{me}\right] - \left[W_{eo} + \rho_{B2} V_{ma} + \rho_{B2} V_{pa}\right] = \left[-\rho_{B1} V_{zne} + \rho_{B2} V_{zsa} - \rho_{B1} V_{zse}\right] + \left[\rho_{B2} V_{sc} + \rho_{B2} V_{tc}\right]$$

Where $\rho_{B1}$ and $\rho_{B2}$ are the bulk densities used to convert sediment volume to sediment weight.

Inputs consist of alluvial sediment delivered from the watershed during floods and estuarine sediment carried into the South Bay from the Central Bay during large flood pulses or by tidal dispersion. These inputs are:

$W_r$ = River inflow
$W_{ei}$ = Inflow of sediment from the estuary to the north
$V_{me}$ = Volume of sediment eroded from the marsh edge

Outputs are loss of sediment to dredging and tidal dispersion to the Central Bay. In addition, the capture of sediment in restored ponds is treated as an output or sediment demand, and the evolution of habitats in these restored areas is calculated separately. These outputs are:

$W_{eo}$ = Outflow of sediment to the estuary to the north
$V_{ma}$ = Accretion of sediment on adjacent marsh plains and restored sites not in the SBSP Restoration Project
$V_{pa}$ = Sediment demand of restored ponds within the SBSP Restoration Project

The Change in Storage terms are the net accumulation or erosion of sediment within each of the geomorphic units. These terms are:

$V_{zne}$ = Sweep zone erosion north of Dumbarton Bridge

$V_{zsa}$ = Sweep zone accretion south of Dumbarton Bridge
$V_{zse}$ = Sweep zone erosion south of Dumbarton Bridge
$V_{sc}$ = Sediment accretion in the subtidal channel, downstream of Calaveras Point
$V_{tc}$ = Sediment accretion in Coyote Creek upstream of Calaveras Point

It is assumed that sediment derived from inputs $W_r$, $W_{ei}$, and $V_{me}$, combined with sediment supplied from the northern sweep zone [$V_{zne}$] is available first for deposition in the restored ponds. An additional supply is made available by the potential erosion of the far South Bay sweep zone [$V_{zse}$]. In the absence of the ponds, this available sediment would otherwise be deposited in the far South Bay subtidal channel [$V_{sc}$] and the sweep zone [$V_{zsa}$] or conveyed out of the system [$W_{eo}$].

Excess sediment beyond the restored pond demand [$V_{pa}$] is assumed to be captured in the subtidal channel [$V_{sc}$] and redeposited on the far South Bay sweep zone [$V_{zsa}$]. This assumption that available sediment will first be captured in the restored ponds is based on the relative effectiveness of the potential sediment sinks in the system. It is expected that the restored ponds will be designed to capture a large portion of estuarine sediment carried in on each flood tide resulting in rapid sedimentation rates. In contrast, sedimentation rates observed in the subtidal channel and far South Bay sweep zone, while significant, are comparatively low. For simplicity, and because Coyote Creek appears to be a relatively efficient sediment sink, it is assumed that sediment deposited in the slough above Calaveras Point is not available for deposition in the ponds.

Each of these geomorphic units has different physical constraints that dictate or limit the rate of potential sediment erosion or accretion. The sections below describe an assessment of how these constraints will operate.

## 5.4 Inputs and Outputs in the Sediment Budget Analysis

### 5.4.1 River Inputs [$W_r$]

McKee and others (2002) estimated the historic long-term average discharge of sediment from the local watersheds north of Dumbarton Bridge. Average discharge of creeks entering far South Bay is derived from the annual suspended sediment loads calculated between water years 1978 and 1987 (Porterfield 1980). For the purposes of this analysis, the same rate of discharge in the next 50 years is assumed. The values for all alternatives are approximately 5 Mt (million tonnes) over 50 years for north of Dumbarton Bridge and approximately 10 Mt over 50 years for the far South Bay.

Flood flows in the creeks discharging to the South Bay are all conveyed through leveed channels directly to the Bay mudflats. With future restoration concentrated adjacent to the mouths of these creeks, it is likely that a high proportion of the sediment discharge will be captured directly in the restored ponds.

### 5.4.2 Estuarine Sediments into and out of the South Bay [$W_{ei}$, $W_{eo}$]

There is a net sediment flux from north to south across the boundary used for the sediment budget analysis (PWA and others 2005). There are two components to this inflow: suspended sediments conveyed by residual wind and tide-driven currents, and turbid water intrusions during large flood events in the Central Valley that stratify the South Bay. This sediment budget analysis was carried out prior to completion of hydrodynamic analyses that would define the magnitude of the residual currents. Southward residual circulation in the shallows of the South Bay have been variously reported as between 0.01-0.02 $ms^{-1}$ (meters per second) (Conomos 1979) and 0.05 $ms^{-1}$ (Walters and others 1985). The amount of sediment entering and leaving the South Bay in suspension therefore constitutes a large uncertainty. For our analysis, a value of 0.03 $ms^{-1}$ is assumed and potential changes in residual circulation due to future changes in bathymetry have not been taken into account.

It is likely that future SSCs in the Bay would be low because the shallows, or sediment sources up-wind or up-current, are not extensive. It is assumed that SSCs would be similar to the average annual values of those in the Central Bay as measured at the Oakland-Bay Bridge, and approximately 30 ppm (parts per million), as shown in Table 5-1 (Buchanan and Ganju 2003; Buchanan and Ganju 2004; Buchanan 2003; Buchanan and Ganju 2002; Buchanan and Ruhl 2001). The residual discharge is calculated for a cross-sectional area across the eastern sweep zone at San Leandro Marina channel and across the western shore sweep zone at Redwood City Harbor channel. This means our assumption for sediment inflow for all alternatives is approximately 10 Mt over 50 years.

**Table 5-1. Average Annual Values of Suspended Sediment Concentration ($mgl^{-1}$, milligrams per liter) measured at the Oakland-Bay Bridge between 1999 and 2002**

| | | 1999 | 2000 | 2001 | 2002 | Min | Max |
|---|---|---|---|---|---|---|---|
| Oakland-Bay Bridge Pier 24 | Mid-depth mean | 25 | 23 | 24 | 20 | 20 | 25 |
| | Near-bottom mean | 33 | 32 | 37 | 32 | 32 | 37 |

Flood flows out of the Delta need to be larger than 100,000 and 300,000 cfs (cubic feet per second) for more than 5 days to stratify and overturn the South Bay south of San Bruno Shoal, depending on spring or neap tide and wind conditions (Conomos 1979); (Williams and Vorster 1987). Assuming that SSCs were similar to the 1998 event monitored at the Oakland-Bay Bridge (approximately 200 ppm), and flows greater than 200,000 cfs for a duration of 5 days will occur at the same frequency as has occurred over the last 50 years, the number of possible intrusion events is approximately sixteen. If it is assumed that the volume of the South Bay within the sediment budget boundary is displaced by these events, the total sediment flux from Central Bay over 50 years is less than approximately 0.5 Mt. This potential source is not significant when compared to other terms, and is therefore not included in the analysis.

Sediment outflow to the north through the subtidal channel can be calculated by the residual northward tidal current and typical SSCs observed in the channel at the San Mateo Bridge. However, for this sediment budget analysis, this sediment outflow is only estimated as the residual of the sediment budget accounting calculations. For simplicity, it is assumed that all excess sediment in the system would be deposited in the subtidal channel and that portion associated with estuarine outflow is not differentiated.

### 5.4.3 Tidal Marsh Edge Erosion [$V_{me}$]

Shoreline erosion rates were estimated as shown in Table 5-2. These were calculated by identifying the linear extent of erodible shoreline and assuming continuation of historic rates of erosion for the eroding areas north and south of Dumbarton Bridge. North of Dumbarton Bridge the rate of erosion was estimated by averaging net erosion of the fringing marsh in locations where the outboard levee south of the Alameda Creek channel had failed approximately 50 years ago. For the area south of Dumbarton Bridge the average erosion rate was estimated by comparing the 2005 digital terrain model (supplied by Terrapoint and USGS) with 19th century T-sheet surveys. Erosion rates along the west shore north of Dumbarton Bridge, and the north shore of far South Bay were assumed to be zero because these shorelines had both advanced and retreated in the historic period. The total sediment input from historic tidal marsh erosion is estimated to be a little over 2 Mt over 50 years.

Lowering of mudflats along the sweep zone north of Dumbarton Bridge would tend to cause accelerated marsh edge erosion in this area. Although this could have significant implications for levee integrity, it is a small term in the sediment budget calculation, and hence acceleration of shoreline erosion was not analyzed in this study.

**Table 5-2. Historic Erosion Rates and Sediment Supply from Erosion of Tidal Marsh Edges**

| Portion of South Bay | Shoreline Length (meters) | | | Historic Erosion Rates (myr$^{-1}$) | Average Sediment Supply (per year) | |
|---|---|---|---|---|---|---|
| | Armored | Erodible Marsh | TOTAL | | m$^3$ | tonnes[e] |
| East Shore North of Dumbarton Bridge | 16,000 | 8,000 | 24,000 | 1.6[a] | 21,760[c] | 32,640 |
| West Shore North of Dumbarton Bridge | 4,900 | 3,570 | 8,470 | Assumed 0 | 0 | 0 |
| South and East Shore of far South Bay | 7,200 | 6,700 | 13,900 | 0.76[b] | 7,640[d] | 11,460 |
| North Shore of far South Bay | 1,350 | 5,000 | 6,350 | Assumed 0 | 0 | 0 |
| TOTALS | 29,450 | 23,270 | 52,720 | N/A | 29,400 | 44,100 |

Notes:

a: erosion rates extracted from approximately 50-year shoreline recession using the line of a levee as position at time 1 and erosion behind levee as position at time 2

b: erosion rates extracted from shoreline positions in 1857, 1897, and 2004

c: sediment supply calculated using average marsh plain elevations of 2.2 m NAVD88 and average mudflat elevations of 0.5 m NAVD88

d: sediment supply calculated using average marsh plain elevations of 2.3 m NAVD88 and average mudflat elevations of 0.8 m NAVD88

e: bulk density assumed to be 1.5 tm$^{-3}$ (tonnes per cubic meter)

### 5.4.4 Marsh Plain Accretion [$V_{ma}$]

There are approximately 3600 ha (hectares) of existing tidal marsh in the South Bay [(Goals Project 1999); (Figure 5.6)]. Approximately 3200 ha are adjacent to the sediment budget boundary defined in Figure 13. With a predicted relative sea-level rise of 0.15 m over the next 50 years (Section 5.5.1), this area could capture approximately 4.8 $Mm^3$ (million cubic meters), or just over 6 Mt of sediment assuming a bulk density of 1.3 $tm^{-3}$ (tonnes per cubic meter). In addition, the 190 ha Island Ponds breached in 2006 are estimated to capture approximately 1.9 Mt and the 190 ha Eden Landing Ecologic Reserve (DFG) restoration could capture as much as 1.4 Mt in this period. This means that the total sediment demand from existing marshes or other restored areas will be approximately 9.5 Mt over 50 years.

### 5.4.5 Sediment Demand in Restored Ponds [$V_{pa}$]

Sediment demand in breached or restored ponds is calculated as the volume of sediment that will accumulate between the initial pond bottom and the elevation of a mature marsh plain at MHHW. This volume is estimated using a simple vertical sedimentation model (MARSH98) (PWA and others 2005) used to predict long-term changes in sedimentation rates in sheltered wind-wave conditions. This model is based on methods derived from Krone (Krone 1987), and calculates the periodic inundation of an intertidal or subtidal marsh area, and the corresponding sediment accumulation that occurs during periods of inundation. The model computes a sediment budget for the water column, accounting for sediment deposition and suspended sediment exchange with an adjacent water body. It is driven by a time series of water surface elevations and a constant SSC for the inundating water.

For each time step, the model begins by calculating the change in height of the water column above the marsh bed. It then calculates the instantaneous sediment budget, accounting for both exchange and sedimentation. The model equilibrates the cell's previous sediment concentration with the sediment concentration of the inflow/outflow, while also calculating the amount of sediment expected to settle out of the water column during that time step. It then increments the marsh bed accordingly, and adjusts the sediment budget of the cell in preparation for the next time step. Figure 14 illustrates how sediment accretes over time in a particular pond.

The initial SSCs under existing conditions for different pond complexes has previously been estimated based on monitoring of earlier restoration sites in the South Bay (PWA and others 2005). It is anticipated that the restoration of the ponds will cause a reduction in the SSC of tidal flows entering the ponds by reducing the amount of sediment in circulation, and retarding long-term sediment demand. To estimate this reduction would require detailed sediment transport and hydrodynamic modeling, which is outside the scope of this analysis. Sensitivity testing has therefore been carried out to test the sensitivity of the pond sediment demand to a 50% reduction of initial SSC values to approximate the effect of lowered SSC on sediment demand. Even with reduced SSCs the ponds fill to colonization elevations within two to three decades of breaching.

Table B1 of Appendix B presents the results of the sediment accumulation calculations for Alternative C for each pond at decadal intervals.

The maximum potential sediment demand of the ponds is the geomorphically defined accommodation space of the ponds. This is the sediment accumulation predicted by the MARSH98 model, less the space required for tidal channels and wave-formed mudflats. The volume of channels in San Francisco Bay tidal marshes has previously been estimated at 15% of the tidal prism. Wave sheltered conditions are assumed.

## 5.5 Change in Storage Terms

### 5.5.1 Relative Sea-Level Rise

Relative sea-level rise is the sum of eustatic (global) sea-level rise, tectonic land movements, and local subsidence. It is important in this study because sea-level rise increases the space available (accommodation space) for sediment to accumulate both in the ponds and outside of them.

*Global Sea-Level Rise*
The rate of eustatic sea-level rise is expected to continue along its 20th century global warming induced accelerated trajectory, possibly attaining an average rate of about 3 $\mathrm{mmyr}^{-1}$ over the next 50 years (2000 to 2050), rising to an average rate of about 5 $\mathrm{mmyr}^{-1}$ over the following 50 years (2050 to 2100) (IPCC 2001). The IPCC global sea-level rise projection is expected to be updated in the 2007 IPCC report, and is likely to be revised upwards based upon ongoing assessment (Meehl and others 2005; Wigley 2005).

*Tectonic Land Movements*
Atwater and others (1977) reported long-term vertical subsidence rates for South Bay. They suggested that Quaternary sediments have sustained at least 100 m of tectonic subsidence in less than 1.5 million years (approximately 1 $\mathrm{mmyr}^{-1}$) relative to the likely elevation of the lowest Pleistocene land surface. Burgmann and others (2006) resolved vertical tectonic land movements around South and Central San Francisco Bay. Adjacent to the South Bay they found two regions of tectonic uplift at rates of 0.5-1.5 $\mathrm{mmyr}^{-1}$. Uplift rates of around 1 $\mathrm{mmyr}^{-1}$ are found in the Santa Cruz Mountains bordering the Santa Clara Valley and between 0.5 and 1.0 $\mathrm{mmyr}^{-1}$ in the vicinity of the Hayward and Calaveras Faults in East Bay. Because of the uncertainty in the estimation of land motion (ranging from 1 $\mathrm{mmyr}^{-1}$ subsidence to 1 $\mathrm{mmyr}^{-1}$ uplift), a value of zero land movement is used in this study.

*Local Subsidence*
Locally to the South Bay, subsidence has occurred in the Santa Clara Valley due to groundwater withdrawals, leaving parts of Alviso at a very low elevation relative to the adjacent sea level. Land subsidence measured at San Jose between 1934 and 1960 exceeded 1.5 m (Poland and Ireland 1988). The rate of groundwater withdrawals has since been reduced and the aquifers artificially recharged. Recent estimates of vertical land movements in the Santa Clara Valley (Schmidt and Burgmann 2003) show that only small amounts of subsidence are likely to be occurring in the South Bay that are due to groundwater extraction. In this analysis it is assumed that no land movement due to groundwater withdrawal takes place.

A relative sea-level rise of 0.15 m over 50 years (3 $mmyr^{-1}$) is used in this geomorphic assessment. This is based on the IPCC mid-range estimates of future global sea-level change over the next 50 years (IPCC 2001) with no land movement component applied.

### 5.5.2 Sweep Zone (Shallow Subtidal and Mudflats) [$V_{zne}$, $V_{zsa}$, $V_{zse}$]

*North of Dumbarton Bridge*

The sweep zone north of Dumbarton Bridge is taken to be the area shallower than 2 m below MLLW and includes USGS sectors E1, E2, E3 shallow, and E1, E2, E3 mid on the east side; and W1 shallow on the west side as shown in Figure 10. Erosion and deposition volumes for each of these areas have been calculated by USGS for the periods 1956-1983 and 1983-2005. These erosion volumes have been normalized to a future 50-year period. While these two periods show largely the same pattern of erosion and deposition, the volume of sediment eroded off the sweep zone changed. For this analysis the volume of sediment eroded between 1956 and 2005 has been taken as representative of rates for the next 50 years. The variability of using the data sets from the 1956-1983 and 1983-2005 time periods has been tested in the sensitivity analysis (Section 7.1). The volume of sediment eroded from the sweep zone using the 1956-2005 data is about 43 Mt over 50 years.

*Far South Bay*

The USGS historical analysis of sedimentation has generated hypsometric curves of the far South Bay that shows the sweep zone to be accreting, but equilibrating with the wave climate, at a constant slope (Figure 12). For this analysis it is assumed that the new restored-pond sediment sinks in the system will preferentially divert sediment that would otherwise accrete in the sweep zone. In addition, it is assumed that recently accumulated sediment can erode at least at the same rate as the sweep zone to the north because shear strength will be lower for freshly deposited sediment.

The net potential erosion of the far South Bay sweep zone over the next 50 years is calculated as follows:

- Calculate the total sediment supply available.
- Add the potential erosional supply from the far South Bay sweep zone assuming erosion to a depth of 0.25 m (average 50-year erosion over the sweep zone north of Dumbarton Bridge).
- Subtract the sediment demand from the ponds, Coyote Creek, and marsh plain accretion.
- Allocate the balance of sediment between re-deposition in the sweep zone and deposition in the subtidal channel. In the absence of hydrodynamic analysis, a 50/50 allocation is assumed.

Data for historic volumetric change in bathymetry used in this analysis is to be published in forthcoming USGS reports (Jaffe and Foxgrover 2006a; Jaffe and Foxgrover 2006b).

### 5.5.3 Subtidal Channel Accretion [$V_{sc}$]

Accretion in the subtidal channel is dependent on the trap efficiency of the channel as compared to the trap efficiency of the sweep zone shallows. These, in turn, are dependent on the accumulated tidal current and wind-wave derived shear stresses. In the absence of hydrodynamic analysis that could better define the sediment transport pathways, it is assumed that the subtidal channel accretion rate is allocated as approximately 50% of the surplus sediment as described in Section 5.5.2.

### 5.5.4 Tidal Sloughs [$V_{tc}$]

It is anticipated that over the next 50 years Coyote Creek upstream of Calaveras Point will silt in to convert all the adjacent mudflats to tidal marsh. The volume of sediment captured is calculated by estimating the accommodation space in this geomorphic unit. This is done by comparing the existing channel cross-section to the predicted equilibrium cross-section for the future tidal prism under each of the alternatives, as shown in Figure 6. It is assumed that this sediment is supplied by what historically has been depositing on adjacent mudflats (USGS sectors E7 shallow and W4 shallow) and by a portion of the deposition in the subtidal channel. The weight of sediment captured by Coyote Creek amounts to between approximately 10 Mt (Alternatives A and B) and 12 Mt (Alternative C) over 50 years.

## 5.6 Converting Weight to Volume [ $\rho_{B1}, \rho_{B2}$ ]

Converting weight of sediment to volume of deposit (volume of sediment plus volume of voids between particles) requires that the bulk density of the material and how this property varies between locations and changes with depth are known. In freshly deposited surface muds the volume of the pore spaces is relatively large. With increasing burial the increasing weight of overlying material progressively expels the pore waters and the density of the mud deposit increases.

A range of typical bulk densities for the deposits of the South Bay have been identified (Table 5-3). Depth-averaged bulk densities in mudflats are interpreted from a number of near-surface samples collected around the South Bay (Pestrong 1965) and from a detailed series of bulk density depth profiles collected at Sonoma Baylands (Corwin 1999). Bulk density for saltmarshes are based upon sediment density profiles collected at two natural marshes in the South Bay region, Bird Island, near Ravenswood and Coyote Creek, near Alviso (Patrick and Delaune 1990). The bulk density of the eroding sweep zone sediments is estimated from a series of logs collected by Caltrans at the San Mateo and Dumbarton Bridges. These logs describe bulk densities of 1.44–1.65 $tm^{-3}$ (average 1.57 $tm^{-3}$) in near surface deposits comprising a mix of muds and shells. Because newly eroded muds will contribute to the accumulation of sediment elsewhere in the estuary, a slightly lower bulk density of 1.5 $tm^{-3}$ is taken to reflect their contribution to the sediment budget.

**Table 5-3. Bulk Densities of Geomorphic Units in the South Bay**

| Deposit | Average Bulk Density ($tm^{-3}$) | Reference |
|---|---|---|
| Mudflat | 1.30 | (Corwin 1999; Pestrong 1965) |
| Tidal marsh (top 1 m) | 1.30 | (Patrick and Delaune 1990; Pestrong 1965) |
| Eroding deposits | 1.50 | Caltrans Logs San Mateo Bridge |

## 5.7 Changes in Extent of Marsh and Offshore Mudflat Habitat

Habitat changes are assessed within the South Bay using areas as defined by the SFEI Goals Project (Goals Project 1999) whose northern limit (South Bay Habitat Boundary) is shown in Figure 13.

Existing tidal marsh area in 2006 is assumed to be approximately the same as that mapped by SFEI in 1997. Marsh area for 2056 is calculated as the 2006 area, plus the area of SBSP restored ponds, plus the Island Ponds and Eden Landing DFG restoration projects, plus accretion of marsh in Coyote Creek minus the loss of fringing marsh due to shoreline erosion.

Existing mudflat in 2006 is calculated as the extent of offshore mudflat north of Dumbarton Bridge as mapped in the 2005 bathymetry. Figures 15 and 16 show the 2005 hypsometric curves for the sweep zone on the west and east side between Dumbarton Bridge and the South Bay Habitat Boundary. Mudflat area in 2056 is calculated as five components:

1. The area of mudflat north of Dumbarton Bridge assumes continued vertical loss of mudflat based on average historic sweep zone lowering of 5 $\text{mmyr}^{-1}$ (0.25 m over 50 years).
2. MLLW is assumed to rise 0.15 m (relative sea-level rise).
3. The area of mudflat in the far South Bay is estimated by the net amount of mudflat accretion or erosion determined by the re-deposited volumes predicted by the sediment budget analysis. Volume change within the sweep zone is translated into change in mudflat area by vertical adjustment of the hypsometric curve for the far South Bay (Figure 12) including relative sea-level rise.
4. The addition to mudflat due to fringing marsh erosion assuming current rates of erosion (estimated to be approximately 100 ha).
5. The conversion of mudflat along Coyote Creek to marsh (estimated to be approximately 200 ha).

Changes in mudflat area calculated in this way, using average hypsometric curves, do not reflect the differential erosion and deposition patterns observed in the South Bay due to wave exposure and tidal currents.

Other types of habitat within the restored ponds – marsh ponds, pans, and tidal channels – used in bird population modeling, are estimated as described in Appendix C. Intertidal bare mud channel edges within mature restored marshes are not included in this analysis of offshore mudflat change. This habitat would account for a portion of the tidal channel area and a few percent of the total area of the tidal marsh.

<This page intentionally left blank>

## 6. ANALYSIS OF RESTORATION ALTERNATIVES

### 6.1 Description of Alternatives and Key Assumptions

The breached ponds in each of the alternatives analyzed are described in the SBSP *Final Alternatives Report* (PWA and others 2006). Tidal restoration will be phased over 50 years and an assumption is made that sediment will be accumulating in some of the ponds over the entire 50-year planning horizon. For simplicity, it is assumed that under the no action alternative pond breaching will occur in a similar manner, although the breaches will occur in an unplanned manner due to levee failure.

It is assumed that all sediment inflows will continue at the same rate as they have historically and the sweep zone north of Dumbarton Bridge will erode at the same average rate observed for the 1956–2005 period.

Sediment demand has been estimated by first calculating the decadal sediment accumulation in each of the pond complexes for estimated existing and 50% of existing SSCs as presented in Table B1 of Appendix B, and illustrated in Figure 14. An assumption is then made that pond breaching will occur in phases. Initially, at Year Zero, 10% of the project area is restored requiring a sediment demand equivalent to 10% of the estimated pond sediment accumulation. After 10 years, an additional 20% of the project area is restored. Sediment demand at this time would be equivalent to 20% of the estimated pond sediment accumulation left after 10% was removed at Year Zero. The total pond area restored at Year 10 is 30%, which approximates to no action (Alternative A) in the restoration project. At Years 20, 30 and 40, additional 20% increments are restored. Hence, at Year 20 a total of 50% of the project area is restored which approximates Alternative B, and at Year 40 a total of 90% is restored which approximates Alternative C. The results of these decadal pond demand estimates are provided in Tables B2 and B3 of Appendix B, enabling calculation of the sediment demand for the range of SSCs at Year 50 as shown in Table 6-1 and detailed in Table B4 of Appendix B. Note the values in Table 6-1 are after adjustment for a 15% reduction to reflect an assumed 85% trap efficiency.

It should be noted that for Alternative A (no action) a slightly smaller sediment demand is assumed, equivalent to 30% of the restoration sediment demand that would occur within 35% of the restored area. This slightly smaller sediment demand relative to actively restored areas is due to the likelihood that unplanned levee failures would result in incomplete tidal exchange and higher wind-wave erosion, retarding evolution from mudflat to tidal marsh inside the ponds, and decreasing sediment demand on the South Bay.

The actual reduction in SSC induced by restoration is uncertain, but as can be seen by Table 6-1, halving of the SSCs results in an approximately 25% reduction in sediment demand in the 50-year period. A mid-range estimate (equivalent to 300 ppm) is used in this analysis.

**Table 6-1. Total Restored Pond Sediment Demand (Mt) for Alternatives A, B, and C Adjusted for an 85% Trap Efficiency**

| | Alternative A | Alternative B | Alternative C |
|---|---|---|---|
| 400 ppm | 20.2 | 35.4 | 58.8 |
| 200 ppm | 16.9 | 27.8 | 41.5 |
| Average | 18.6 | 31.6 | 50.1 |

In the absence of hydrodynamic modeling analyses that would help define sediment transport pathways, it is assumed that:

1. The breached ponds are efficient sediment sinks, capturing a large proportion of estuarine sediments brought in on each flood tide. This is in contrast with sediment accumulation in the subtidal channel and on the sweep zone where only a small percentage of suspended sediment in the water column accumulates on a tidal cycle. In the sediment budget computation, it is therefore assumed that pond sediment demand is filled first.
2. The Eden Landing and Ravenswood ponds, comprising approximately 18% of the total sediment demand, would have negligible affects on the erosion of the adjacent sweep zone, but would capture sediment that would otherwise be available for mudflat accretion in the far South Bay.
3. Sediment available for deposition in the Alviso ponds consists of excess sediment that would otherwise be captured in the subtidal channel and sediment that otherwise would be accreting on the sweep zone shallows and mudflats.
4. After deducting sediment captured in the restored ponds, the remaining sediment is allocated to channel or sweep zone deposition based on a 50/50 ratio. Under historic conditions this ratio has been approximately 70/30. However, it is anticipated that with future erosion of the sweep zone and filling of the subtidal channel the relative trap effectiveness of these geomorphic units will change.

The depth, and hence, amount of erodible sediment across the sweep zone in the far South Bay, is uncertain. The same erodible depth as the 50-year historic eroded depth of the sweep zone north of Dumbarton Bridge is therefore used (approximately 0.25 m).

## 6.2 Results: Habitat Changes

Table 6-2 shows the sediment budget calculations and Tables 6.3 and 6.4 show the resulting changes in habitat area rounded to the nearest square kilometer.

Table 6-2 shows that restoration of the South Bay ponds will add a large new sediment sink to the South Bay system. For Alternative C, the total sediment input to the system is approximately 78 Mt of which the ponds demand is 50 Mt. This equates to a sediment demand from the ponds that is approximately 64% of the expected total sediment supply over the 50-year implementation period.

Table 6-3 shows existing mudflat areas of 25 $km^2$ and 23 $km^2$ north and south of Dumbarton Bridge, respectively; Coyote Creek contains another 2 $km^2$ making a total mudflat area of 50 $km^2$ south of San Leandro Marina channel. These data were calculated from the 2005 DTM supplied by the USGS, for elevation zones between MLLW and colonization elevations of 1.0 MLLW north of Dumbarton Bridge and 1.25 m MLLW south of Dumbarton Bridge (this estimate appears to be slightly smaller than the USGS data shown in Figure 9). The table shows that implementation of Alternative A (no action) will lead to an estimated total loss of approximately 14 $km^2$ or 28% of the existing offshore mudflats over the next 50 years, assuming continuation of trends observed over the last 50 years. With implementation of Alternatives B and C of the restoration project a further mudflat loss of up to 10 $km^2$ could occur, resulting in a total reduction of approximately 50% of existing offshore mudflats, over the next 50 years in South Bay.

North of Dumbarton Bridge the type of tidal restoration alternative adopted will have very little effect on the rate of loss of adjacent mudflats. For all Alternatives, including no action, it is expected that total mudflat losses north of Dumbarton Bridge over the next 50 years would be approximately 15 $km^2$ or 60% of existing mudflats (Table 6-3). In far South Bay, where mudflats have previously been stable or expanding, it is predicted that no action (Alternative A) would result in a gain of 2 $km^2$ of mudflat over the next 50 years, Alternative B would result in no loss and Alternative C an 8 $km^2$ loss. Hence, compared to the no action alternative, tidal restoration under Alternative B is predicted to result in the loss of 2 $km^2$ of mudflats, while Alternative C is predicted to result in the loss of 10 $km^2$ of mudflats.

Table 6-4 shows the projected tidal marsh areas over the next 50 years in the South Bay, south of San Leandro Marina channel. The table shows that all the alternatives return an increase in tidal marsh within the South Bay. Under no action (Alternative A), an increase of 19 $km^2$ or 45% of existing area is predicted. Alternatives B and C are predicted to result in a total of 72 $km^2$ and 89 $km^2$ of tidal marsh in the South Bay, respectively. These equate to increases of 70% and 110% compared to the area of tidal marsh (42 $km^2$) that exists today.

**Table 6-2. Sediment Budget Analysis for Alternatives A, B, and C**

| Row No | | Alternative A | Alternative B | Alternative C | Calculation |
|---|---|---|---|---|---|
| 1 | Estuary Input (Mt) | -9.93 | -9.93 | -9.93 | |
| 2 | River Input (Mt) | -14.90 | -14.90 | -14.90 | |
| 3 | Marsh Edge Erosion (Mt) | -2.21 | -2.21 | -2.21 | |
| 4 | Marsh Plain Accretion (Mt) | 9.59 | 9.59 | 9.59 | |
| 5 | Sediment Available to System (Mt) | -17.45 | -17.45 | -17.45 | (1) + (2) + (3) + (4) |
| 6 | North Dumbarton Bridge Sweep Zone Erosion (Mt) | -42.54 | -42.54 | -42.54 | |
| 7 | Far South Bay Sweep Zone Erosion (Mt) | -8.63 | -8.63 | -8.63 | |
| 8 | Coyote Creek Channel Accretion (Mt) | 10.41 | 10.41 | 11.92 | |
| 9 | Sediment Available to Ponds (Mt) | -58.21 | -58.21 | -56.70 | (5) + (6) + (7) + (8) |
| 10 | Pond Demand (Mt) | 18.55 | 31.60 | 50.15 | |
| | | | | | |
| 11 | Excess Sediment (Mt) | -39.66 | -26.61 | -6.54 | (9) + (10) |
| | | | | | |
| 12 | Far South Bay Sweep Zone Accretion (Mt) | 19.83 | 13.30 | 3.27 | (11) x 50% |
| | | | | | |
| 13 | Net Change of far South Bay Sweep Zone (Mt) | 11.20 | 4.68 | -5.35 | (7) + (12) |
| 14 | Net Vertical Movement Relative to 2005 Elevation (m) | 0.37 | 0.16 | -0.18 | (13) / 1.3*/23.0** |
| 15 | Net Vertical Movement Relative to 2056 MHHW (m) | 0.22 | 0.01 | -0.33 | (14) - 0.15 *** |
| 16 | Far South Bay Mudflat Area (km$^2$) | 25.13 | 23.12 | 15.41 | based on adjustment of 2005 hypsometric curve for far South Bay |
| 17 | Net Vertical Erosion North of Dumbarton Bridge (m) | -0.25 | -0.25 | -0.25 | |
| 18 | Net Vertical Lowering Relative to 2056 MHHW (m) | -0.40 | -0.40 | -0.40 | (7) - 0.15*** |
| 19 | North Dumbarton Bridge Mudflat Area (km$^2$) | 9.55 | 9.55 | 9.55 | based on adjustment of 2005 hypsometric curve for north of Dumbarton Bridge |
| | | | | | |
| 20 | Marsh Conversion to Mudflat (km$^2$) | 1.00 | 1.00 | 1.00 | |
| | | | | | |
| 21 | Total Mudflat Area (km$^2$) | 35.7 | 33.7 | 26.0 | **(16) + (19) + (20)** |

* = bulk density (tm $^{-3}$)

** = approximate area of far South Bay mudflats(km$^2$)

*** = relative sea-level rise over 50 years (m)

**Table 6-3. Projected Offshore Mudflat Area**

| Mudflat Area (square km's) | | | | | |
|---|---|---|---|---|---|
| | North of Dumbarton Bridge | Far South Bay | Coyote Creek | Marsh Conversion to Mudflat | Total Area |
| 1956 | - | - | - | - | 58[1] |
| 2006 Existing Conditions | 25 | 23 | 2 | n/a | 50 |
| 2056 Alternative A | 10 | 25 | 0 | 1 | 36 |
| 2056 Alternative B | 10 | 23 | 0 | 1 | 34 |
| 2056 Alternative C | 10 | 15 | 0 | 1 | 26 |

[1] Value from USGS (Foxgrover and others 2004; Jaffe and Foxgrover 2006a; Jaffe and Foxgrover 2006b).

**Table 6-4. Projected Tidal Marsh Area**

| Tidal Marsh Area (square km's) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Scenario | Existing Marsh | Restored Marsh | | | Change in Fringing Marsh | | |
| | | Island Ponds | Eden Landing ER | SBSP | [3]Eroded | [2]Accreted | Total |
| 2006 Existing conditions | [1]38 | 2 | 2 | | | | 42 |
| 2056 Alternative A | 38 | 2 | 2 | 18 | -1 | 2 | 61 |
| 2056 Alternative B | 38 | 2 | 2 | 29 | -1 | 2 | 72 |
| 2056 Alternative C | 38 | 2 | 2 | 46 | -1 | 2 | 89 |

[1] From SFEI Goals Project 1999 “present” conditions (Goals Project 1999)

[2] Sectors E7 shallow and W4 shallow in USGS bathymetric analysis

[3] Assumes bayfront levees intact

Table 6-5 and Figure 17 illustrate total changes in habitat area relative to historic landscape-scale long-term trends.

**Table 6-5. Long-term Intertidal Habitat Changes south of the San Leandro Marina channel**

| | **Area $km^2$** | |
|---|---|---|
| **Year** | **Offshore Mudflat** | **Tidal Marsh** |
| 1858[1] | 69 | 230 |
| 1898[1] | 64 | 195 |
| 1931[1] | 61 | 90 |
| 1956[1] | 58 | 55 |
| 1983[1] | 46 | 35 |
| 2005 | 50 | 42[2] |
| 2056 Alt A. | 36 | 61 |
| 2056 Alt B. | 34 | 72 |
| 2056 Alt C | 26 | 89 |

1 [1] Data from Foxgrover and others (2004) and USGS (Jaffe and Foxgrover 2006a; Jaffe and Foxgrover 2006b)

2 [2] Assumed 38 $km^2$ (Goals Project 1999) (their Figure 5-6) but adding Island Ponds and Eden Landing DFG (4 $km^2$)

# 7. LIMITATIONS OF ANALYSIS

## 7.1 Sensitivity Analysis

There are considerable uncertainties in the estimation of sediment budget components, assumptions concerning sediment dynamics, and assumptions concerning the morphologic response to sediment surpluses and deficits in this analysis. The significance of these uncertainties can be tested by examining how the range of possible values or different assumptions would affect the estimate of habitat change. This sensitivity analysis provides insight into the conditions that could significantly adversely affect sediment availability and rate of restoration of tidal marsh in the restored ponds. This analysis also informs the design of the adaptive management program.

In some of the sensitivity runs, pond demand exceeds available sediment. Under these circumstances the deficit has been allocated 50% to sweep zone erosion and 50% to subtidal channel erosion.

The following are the range of values tested for significance or assumptions in the sediment budget calculations:

1. River inflow $W_r$ *Estimated value +/- 50%.*
   This range reflects long-term climatic variability and estimates of sediment delivery. In particular, this range accounts for a potential four-fold reduction in river supply to far South Bay (Guadalupe River and Coyote Creek) postulated by Schoellhamer and others (2006) compared to the estimates of Porterfield (Porterfield 1980), assuming river inputs north of Dumbarton Bridge remain the same.

2. Estuarine sediments into South Bay $W_{ei}$ *= zero, +100% or +300% of estimated value.*
   This sediment inflow is dependent on the product of the net southward residual circulation along the shallows and the average SSC in the Central Bay and South Bay. Mid-range estimates of 0.03 $ms^{-1}$ and 30 ppm were used for these parameters. A zero value for the inflow term implies very low residual currents and/or very low SSC in the Central Bay. Plus 100% implies either residual currents of 0.06 $ms^{-1}$ or average SSC of 60 ppm or combinations in between. Plus 300% implies either residual currents of 0.12 $ms^{-1}$ or average SSC of 120 ppm or combinations in between. These estimates can be refined in the future based on the hydrodynamic modeling results.

3. Shoreline erosion $V_{me}$ *= 200% of estimated value.*
   Although this is a relatively small term in the sediment budget calculation it has more significant implications for changes in habitat extent and quality, and affect on levee integrity. No systematic analysis of shoreline erosion, or its relationship to wave power and offshore mudflat profile, has yet been made. The estimate used is based on historic erosion rates that may be biased to low values because of the presence of abandoned levees and offshore mudflat accretion. Future erosion rates for the same wave climate are more likely to accelerate with net mudflat lowering and disintegration of shoreline levees. Approximately 29 km of shoreline in the South Bay are exposed levees without

fringing marsh (Table 6-2). These levees have arrested shoreline retreat over the last century that otherwise might have converted more than 5 $km^2$ of natural marsh to mudflat assuming current rates of erosion.

4. Deposited sediment bulk density *Value of 1.50* $tm^{-3}$
   For the best estimate, deposited sediment with a bulk density of 1.30 $tm^{-3}$ is differentiated from eroded sediment with a bulk density of 1.50 $tm^{-3}$. Over time, freshly deposited mud consolidates, so a uniform bulk density of 1.50 $tm^{-3}$ was evaluated. The major result is to increase sediment demand in the restored ponds by approximately 15%.

5. Suspended sediment concentrations. *No reduction in average SSC (e.g. 400 ppm), or maximum reduction to 50% (e.g. 200 ppm).*
   A lowering in sediment demand from the restored ponds is tested that reflects how restoration is likely to reduce SSC in the whole South Bay. This was based on a mid-range estimate of between 100% and 50% of projected values over the project timeframe. Assuming no lowering takes into account the possibility that SSCs may be higher than anticipated, causing more rapid sedimentation. However, there is a negative feedback mechanism that limits the lower SSC level. As SSC reduces, sediment demands in the restored ponds are reduced, limiting the reduction in estuary-wide SSC. A 50% reduction is an approximate lower limit because accretion rates in the Ravenswood complex "stall" at an elevation significantly below MHHW at this level (Appendix B) thereby reducing demand.

6. Sweep zone erosion north of Dumbarton Bridge $V_{zne}$
   The variability in erosion rates is characterized using data from 1956-1983 (high erosion) and 1983-2005 (low erosion). The same general pattern of erosion was observed in these two periods (Figure 11); however, the total amount of sediment supplied by sweep zone erosion changed from 55 to 27 Mt. There is a discrepancy in the 1983-2005 sediment budget data as it indicates subtidal channel and far South Bay sweep zone deposition exceed all available supplies. This discrepancy prompted use of the longer 49-year period (1956-2005) as the basis for the sediment budget analysis.

7. Erodible depth of the far South Bay sweep zone. *No erosion or erosion to 0.5 m.*
   Zero erosion means that the shallows and mudflats can accrete but not erode below 2005 elevations. The 0.5 m erodible depth means that erosion can occur at twice the historic rate observed north of Dumbarton Bridge.

8. Sediment accretion/erosion in the subtidal channel. *20% of available sediment is first deposited in the subtidal channel.*
   This assumption reflects significant unknowns concerning the sediment dynamics of the system and the trap efficiency of the channel as compared to the trap efficiency of the restored ponds. These, in turn, are dependent on the combined tidal current and wind-wave derived shear stresses. In the absence of hydrodynamic analysis that could better define the sediment transport pathways, it is assumed that restored pond trap efficiency is very high – as is documented in many Bay Area

restoration projects (PWA 2004) – and that the trap efficiency of the subtidal channel is very low as indicated by sedimentation rates of about 30 mmyr$^{-1}$, less than 10% of the potential deposition rate observed in restored sites. Over the next 50 years, it is anticipated that the subtidal channel will silt in close to its equilibrium geometry as shown in Figure 6. This means that the subtidal channel trap efficiency and sedimentation rate are more likely to diminish over time.

9. Best case and worst case scenarios. These scenarios aggregate all of the extremes from the range of variables that favor or disfavor sediment supply – excluding accelerated sea-level rise and +300% estuary input. These scenarios were calculated to illustrate the most extreme range of possibilities in habitat change.

10. Increased acceleration of rise in relative sea level. *Doubling of assumed accelerated rate to 0.3 m in 50 years*.
    This uncertainty was tested separately because it appears to have the largest potential impact on habitat areas. Doubling the rate of sea-level rise still falls within the range of predictions referenced by the IPCC (IPCC 2001).

## 7.2 Results

Table 7-1 shows the results of the sensitivity analysis applied to the independent variables for Alternative C. This table illustrates how altering each independent variable within the sensitivity range described above affects the primary dependent variable – the area of offshore intertidal mudflat. An assumption has been made that the elevation of MLLW does not change upon opening of the ponds, except for change due to relative sea-level rise. There is the potential for further increase in elevation of MLLW due to changes in hydrodynamics.

In general, the range of each individual independent variable tested affects the predicted 2056 offshore mudflat estimate of 26 km$^2$ by approximately plus or minus 3 km$^2$. Two of the largest uncertainties concern the inflow of sediment from Central Bay and the impact of future relative sea-level rise. Quadrupling the estimated estuarine inflow of sediment would, by itself, result in a total mudflat area of approximately 35 km$^2$ in 2056, an incremental increase of 9 km$^2$. By contrast, doubling the estimated rise of sea level to 0.3 m would, by itself, cause an incremental loss of about 8 km$^2$ of intertidal mudflat, and the offshore mudflat area north of Dumbarton Bridge would be reduced to about 6 km$^2$ from 25 km$^2$ in 2006. This large reduction would also have a significant effect on shoreline erosion rates. The impact on mudflat area would be similar if MLLW increased in elevation by 0.15 m due to hydrodynamic changes, over and above the best estimate of relative sea-level rise.

Under the "worst case" combination and "best case" combination of values (excluding quadrupling estuary input and doubling relative sea-level rise) the range of possible predictions is 13 to 37 km$^2$, as compared to approximately 50 km$^2$ presently. This means that even under the most optimistic assumptions, a significant loss in mudflat area in the South Bay is anticipated. The predicted area of mudflat in the far South Bay is greatly dependent on values and assumptions selected in the analysis. The prediction of mudflat area north of Dumbarton Bridge is much less sensitive.

Another large uncertainty concerns our understanding of sediment dynamics and deposition patterns in the far South Bay. In the absence of hydrodynamic analysis it is assumed that because of the high trap efficiency of restored ponds relative to the very low trap efficiency of the subtidal channel, sediment would be preferentially captured first in the restored ponds. However, the sensitivity analysis shows that if 20% of available sediment was first captured in the deep channel, there could be a substantial lowering of the sweep zone and a reduction in mudflat area in the far South Bay. In contrast, the variability in erosion rates of the sweep zone north of Dumbarton Bridge as reflected in the two survey periods, 1956-1983 and 1983-2005, the variability of river sediment inputs, and the variability of estuarine sediment inputs affects the mudflat area prediction by approximately plus or minus 10%.

Table 7-1 also illustrates the potential sensitivity of the pond demand relative to the total sediment input to the system. Using the cumulative best scenario, the pond demand for sediment of 50 Mt is approximately 40% of the total sediment input to the system. Using the cumulative worst scenario, the pond's demand is approximately 135% of the total sediment input. When sediment demand exceeds supply (e.g. cumulative worst scenario), it has been assumed there will be accelerated erosion of offshore mudflats in the far South Bay.

**Table 7-1. Sensitivity Analysis**

| Sensitivity Alternative C (all values in Mt unless otherwise specified) | Estuary Input (Wei) | South Bay River Input (Wr) | Tidal Marsh Edge Erosion (Vme) | Marsh Plain Accretion (Vma) | SBSP Pond Demand (Vpa) | North Dumbarton Bridge Sweep Zone Erosion (Vzn) | Potential Far South Bay Shallows Erosion (Vze) | Tidal Channel Deposition (Vtc) | Balance of Supply v Demand | Far South Bay Shallows Redistribution | Subtidal Channel Redistribution | Net Sweep Zone Erosion | Net Vertical Change Relative to 2005 Elevation (cm) | Net Vertical Change Relative to 2056 MHHW (cm) | Far South Bay Mudflat Area (km$^2$) | North Dumbarton Mudflat Area (km$^2$) | Marsh Conversion to Mudflat (km$^2$) | Total Mudflat Area (km$^2$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Best Estimate: 1956-2005 | -9.9 | -14.9 | -2.2 | 9.6 | 50.1 | -42.5 | -8.6 | 11.9 | 6.6 | 3.3 | 3.3 | -5.4 | -17.9 | -32.9 | 15.4 | 9.6 | 1.0 | 26.0 |
| 1956-1983 | -9.9 | -14.9 | -2.2 | 9.6 | 50.1 | **-55.1** | **-11.9** | 11.9 | 22.4 | 11.2 | 11.2 | -0.7 | -2.2 | -17.2 | 18.7 | 9.0 | 1.0 | 28.7 |
| 1983-2005 | -9.9 | -14.9 | -2.2 | 9.6 | 50.1 | **-27.1** | **-6.0** | 11.9 | -11.5 | -5.8 | -5.8 | -11.8 | -39.3 | -54.3 | 11.8 | 10.7 | 1.0 | 23.5 |
| River Input +50% | -9.9 | **-22.4** | -2.2 | 9.6 | 50.1 | -42.5 | -8.6 | 11.9 | 14.0 | 7.0 | 7.0 | -1.6 | -5.4 | -20.4 | 17.9 | 9.6 | 1.0 | 28.5 |
| River Input -50% | -9.9 | **-7.5** | -2.2 | 9.6 | 50.1 | -42.5 | -8.6 | 11.9 | -0.9 | -0.5 | -0.5 | -9.1 | -30.4 | -45.4 | 13.4 | 9.6 | 1.0 | 24.0 |
| Estuary Input 0% | **0.0** | -14.9 | -2.2 | 9.6 | 50.1 | -42.5 | -8.6 | 11.9 | -3.4 | -1.7 | -1.7 | -10.3 | -34.5 | -49.5 | 12.7 | 9.6 | 1.0 | 23.3 |
| Estuary Input +100% | **-19.9** | -14.9 | -2.2 | 9.6 | 50.1 | -42.5 | -8.6 | 11.9 | 16.5 | 8.2 | 8.2 | -0.4 | -1.3 | -16.3 | 18.9 | 9.6 | 1.0 | 29.5 |
| Tidal Marsh Edge +200% | -9.9 | -14.9 | **-6.6** | 9.6 | 50.1 | -42.5 | -8.6 | 11.9 | 11.0 | 5.5 | 5.5 | -3.1 | -10.5 | -25.5 | 16.6 | 9.6 | 1.0 | 27.2 |
| Bulk Density 1.5 | -9.9 | -14.9 | -2.2 | **11.1** | **57.9** | -42.5 | -8.6 | **13.8** | -4.5 | -2.2 | -2.2 | -10.9 | -36.3 | -51.3 | 12.4 | 9.6 | 1.0 | 23.0 |
| 200 ppm | -9.9 | -14.9 | -2.2 | 9.6 | **41.5** | -42.5 | -8.6 | 11.9 | 15.2 | 7.6 | 7.6 | -1.0 | -3.4 | -18.4 | 18.4 | 9.6 | 1.0 | 29.0 |
| 400 ppm | -9.9 | -14.9 | -2.2 | 9.6 | **58.8** | -42.5 | -8.6 | 11.9 | -2.1 | -1.0 | -1.0 | -9.7 | -32.3 | -47.3 | 13.0 | 9.6 | 1.0 | 23.6 |
| Far South Bay Erosion = 0 m | -9.9 | -14.9 | -2.2 | 9.6 | 50.1 | -42.5 | **0.0** | 11.9 | -2.1 | -1.0 | -1.0 | -1.0 | -3.5 | -18.5 | 18.3 | 9.6 | 1.0 | 28.9 |
| Far South Bay Erosion = 0.5 m | -9.9 | -14.9 | -2.2 | 9.6 | 50.1 | -42.5 | **-17.3** | 11.9 | 15.2 | 7.6 | 7.6 | -9.7 | -32.3 | -47.3 | 13.0 | 9.6 | 1.0 | 23.6 |
| Estuary Input +300% | **-39.7** | -14.9 | -2.2 | 9.6 | 50.1 | -42.5 | -8.6 | 11.9 | 36.3 | 18.2 | 18.2 | 9.5 | 31.9 | 16.9 | 24.8 | 9.6 | 1.0 | 35.4 |
| Relative Sea-Level Rise x2 | -9.9 | -14.9 | -2.2 | **16.3** | **57.9** | -42.5 | -8.6 | 11.9 | -7.9 | -4.0 | -4.0 | -12.6 | -42.1 | **-72.1** | 11.3 | 5.9 | 1.0 | 18.2 |
| Cumulative Worst | **0.0** | **-7.5** | -2.2 | **11.1** | **67.8** | **-27.1** | **0.0** | **13.8** | -55.9 | -28.0 | -28.0 | -28.0 | -93.5 | -108.5 | 3.0 | 9.0 | 1.0 | 13.0 |
| Cumulative Best | **-19.9** | **-22.4** | **-6.6** | 9.6 | **41.5** | **-55.1** | **-17.3** | 11.9 | 58.2 | 29.1 | 29.1 | 11.9 | 39.7 | 24.7 | 25.2 | 10.7 | 1.0 | 36.9 |
| 20% Captured by Subtidal | -9.9 | -14.9 | -2.2 | 9.6 | 50.1 | -42.5 | -8.6 | 11.9 | **-4.8** | -4.8 |  | -13.4 | -44.9 | -59.9 | 10.8 | 9.6 | 1.0 | 21.4 |

Notes: Bold indicates independent variable change

## 7.3 Method of Analysis

It is recognized that developing morphologic predictions is a new applied science (Wilcock and Iverson 2003), and this sediment budget geomorphic analysis is a first approximation of potential habitat change. A prior review of this problem by the NOAA Airport Expansion Science Review Panel (NOAA Science Panel II 2002) has suggested that a range of tools be applied to inform the understanding of impacts of major human alterations of the estuary on habitat or sediment supply constraints.

It is possible to integrate the “top-down” geomorphically-based sediment budget analysis described here, with hydrodynamic models that account for changes in SSC and changing estuarine morphology (EMPHASYS Consortium 2000). An example of the simplest type of this model is the UP-sediment model (Lionberger and others 2006; Uncles and Peterson 1995). A better understanding of sediment dynamics within the South Bay might also be obtained by incorporating a sediment transport module within the DELFT3D hydrodynamic modeling analysis now being undertaken for the Project. In addition, it is possible to complement the top-down geomorphic analysis described in this report with a “bottom-up morphologic” model that fully integrates sediment dynamics and hydrodynamics, for example using DELFT3D’s - Online Morphology module (WL | Delft Hydraulics 2003).

## 8. IMPLICATIONS FOR ADAPTIVE MANAGEMENT

### 8.1 Adaptive Management Tools

#### 8.1.1 General

Adaptive management is an integral component of the restoration project and is described in Trulio and Clark (Trulio and Clark 2005). A key part of the adaptive management program is to anticipate and mitigate potential adverse impacts by providing decision makers with improved understanding and predictions of how restoration actions affect important resources. This information is obtained both through monitoring and executing applied studies and experiments designed to narrow the range of uncertainties concerning potential outcomes of restoration actions.

This report predicts a significant net loss of mudflat habitat in the South Bay under the no action alternative, as well as an incremental loss due to tidal restoration of the ponds. It may be possible, through the adaptive management program, not only to mitigate the loss of important ecologic functions provided by the mudflats due to the project, but also to compensate for some of the mudflat losses that will be occurring with or without the project. There are a number of management tools available to accomplish this.

#### 8.1.2 Phasing

Staggering the timing of pond restoration (as assumed in the pond sediment demand assessment, Section 6.1) has the following beneficial effects:

- Sediment demand rate is better matched to the rate of supply, minimizing impacts to the far South Bay mudflats.
- Phasing allows for successive generations of adaptive management experiments to better understand how the geomorphic system is evolving.
- Phasing creates a longer period where there can be extensive transitional mudflats within the restored ponds. Typically, ponds can take several decades to evolve from intertidal mudflats to fully vegetated marsh. During this time, the mix of habitats change – as is illustrated in Figure 18. With appropriate planning, the project phasing might be designed to allow for no net loss of mudflat area over a period of two to three decades.

#### 8.1.3 Mudflat Restoration

Mudflat losses could be compensated for by designing some ponds or portions of ponds, as permanent mudflats. This would not only mitigate for loss of mudflat area, but would also reduce sediment demand and hence the extent of mudflat loss. Permanent mudflats could be achieved in those ponds that are subsided below colonization elevations and have large wind fetches. In addition, large wind fetches could be created by removing internal levees and berms and/or by removing bayfront levees oriented towards the predominant wave direction. Alternatively, it might be possible to artificially replenish eroding offshore mudflats by recharging with dredged materials (Healy and others 2001).

### 8.1.4 Restoring Natural Shorelines

Recreating natural erodible shorelines adds to the sediment supply and allows for fringing marsh to convert to mudflat. These natural shorelines, which include beaches, wrack lines and Bay-edge pans are important habitats. Natural shorelines can be achieved by first breaching bayfront ponds, and allowing tidal marshes to form, and then removing bayfront levees.

### 8.1.5 Reducing Sediment Demand

Sediment demand and mudflat loss could be reduced by:

- Using imported fill to raise the elevations of the subsided ponds to colonization elevations
- Restoring ponds as intertidal mudflat habitat
- Prioritize tidal restoration to high elevation ponds

## 8.2 Key Uncertainties

This sediment budget analysis has identified the following key uncertainties that affect adaptive management decisions:

1. Bathymetric Change

The largest source of sediment within the South Bay is the erosion of the shallows north of Dumbarton Bridge. Appropriate monitoring of these erosion rates will allow updating and better predictions of long-term habitat change, and developing and improving existing models will help to better understand the factors that control erosion.

2. Sediment Dynamics within the South Bay

Uncertainties in assumptions concerning average SSCs, residual circulation and sediment supply from the Central Bay, and the relative effectiveness of accommodation space in the restored ponds and oversized subtidal channels, could have a significant effect on mudflat loss predictions in the far South Bay.

3. Sediment Demand in Restored Ponds

Sediment demand in restored ponds is the largest component of the sediment budget and can be verified by mapping long-term sedimentation rates in restored areas of different ages around the South Bay and by measuring changes in bulk density of the deposited mud.

4. Sea-Level Rise

Acceleration in the rate of relative sea-level rise will have a significant impact on the mix of habitats throughout San Francisco Bay. While this is an external variable, it might affect management decisions on the types of habitat to restore in future phases of the project.

5. Wind-Wave Effects
Restoration of interim or permanent mudflats within the ponds may be an important adaptive management tool to mitigate or anticipate South Bay mudflat losses. Characterization of the local wind climate and a better definition of how wind waves generated by different fetch lengths affect sediment accretion and colonization rates would inform management decisions.

6. Shoreline Erosion
Although this is a relatively small term in the sediment budget, definition of shoreline erosion rates can have significant implications for adaptive management decisions. In particular, the relationship between the lowering of offshore mudflats and marsh edge and bayfront levee erosion rates needs to be defined.

7. River Inputs in far South Bay
A better understanding of river inputs south of Dumbarton Bridge is needed because restoration sites are adjacent to creek mouths and it is likely that most of the locally-discharged sediment will be captured in the restoring ponds.

## 8.3 Monitoring

The following are important monitoring requirements for informing predictions of habitat change and adaptive management decisions for future phases of the restoration project:

1. Landscape-Scale Habitat Mapping
This can be achieved using satellite imagery at low tide at decadal intervals with ground truthing of key habitat types.

2. Bathymetric Surveys
Replication of the 2005 LiDAR and bathymetric surveys at 10- or 20-year intervals will allow for updating habitat evolution predictions, identify mudflat and shoreline change trends, and provide the basis for updating hydrodynamic analyses of the Bay.

3. Suspended Sediment Concentrations
Continuation of long-term SSC measurement at the San Mateo Bridge, Dumbarton Bridge, stations in the far South Bay, and on the shallows will allow for identification of long-term trends, and calibration of a sediment dynamics model. This would include continued monitoring of sediment fluxes at the northern boundary of the South Bay and at key locations in the South Bay channels and shallows.

4. Tidal Characteristics
Establishing a long-term tidal record in the far South Bay will allow identification of trends in tidal characteristics that can also provide input to a sediment dynamics model.

5. Wind Climate

Establishing a long-term weather station at the Bay margin in the lower end of the South Bay will allow development of a long-term wind climate. This would assist in interpreting interannual variations in SSC and long-term shoreline erosion rates.

6. River Sediment Supply

Long-term monitoring of river sediment supply at the river mouths will allow for a better understanding of the magnitude of river sediment discharged into the Bay.

7. Benchmark Surveys

Periodic resurveys of benchmarks with appropriate spatial coverage to represent net subsidence and/or uplift in the planning area would allow monitoring of trends in relative sea-level rise and more accurate estimates of long-term sediment demand.

## 8.4 Applied Studies

The following experiments or studies could be incorporated in the Phase 1 restoration project design or carried out of an early stage of project implementation:

1. Sediment Accretion Rates in Restored Ponds

Long-term sediment accretion rates and average SSCs can be confirmed by measuring total and net accretion, and bulk density profiles, in a variety of existing restoration sites of different ages within the South Bay. These sites include Faber Tract (34 years), Warm Springs (20 years), Cooley Landing (5 years), and Island Ponds (0 years). Accretion can be measured as transects and/or LiDAR surveys.

2. Affect of Internally-Generated Wind Waves on Sediment Accretion

Interim or permanent mudflat creation can be tested by designing for different fetch lengths in tidally restored ponds in Phase 1 (e.g. Pond A6). Differential mudflat accretion rates and colonization elevations would be measured in adjacent experimental cells with different fetch lengths.

3. Affect of Removal of Bayfront Levee on Mudflat Accretion

The effect of removing a section of bayfront levee to test mudflat response to maximum wave exposure could be incorporated in a bayfront tidal restoration site, such as Pond A6.

4. Relationship between Offshore Mudflat Elevation and Natural Shoreline Erosion Rate

Using existing historical data of shoreline position obtained from a variety of sources, marsh edge retreat rates could be mapped and correlated with offshore mudflat and sweep zone profiles, and dominant wave power, to establish a predictive method for identifying future rates of shoreline retreat. In addition, simple baseline marsh edge and mudflat transects could be established and monitored to test and improve predictions.

5. Relationship between Offshore Mudflat Elevation and Bayfront Levee Erosion Rates

A review of historical sweep zone elevation change and historic levee failures could be made in conjunction with a bayfront levee assessment to determine the relationship between offshore mudflat lowering and the rate of levee erosion.

6. Refinement Of Prediction Of Habitat Response By Modeling Sediment Dynamics

Modeling of sediment dynamics would allow for improved predictions of habitat change by better definition of residual circulation and sediment supply from the Central Bay, sediment movement between different geomorphic units within the South Bay, apportionment of sediment supply to different sinks within the Bay, changes in SSCs due to pond restoration, and definition of mudflat and shorelines most susceptible to erosion. This study would be supported by a study of sediment fluxes at the seaward boundary and at Dumbarton Bridge where the cross-section is smallest.

<This page intentionally left blank>

## 9. REFERENCES

Allen JRL. 1990. The Severn estuary of southwest Britain: its retreat under marine transgression, and fine sediment regime. Sedimenary Geology 66:13-28.

Allen JRL. 2000. Morphodynamics of Holocene salt marshes: a review sketch from the Atlantic and Southern North Sea coasts of Europe. Quaternary Science Reviews 19:1155-1231.

Anthony E, Orford J. 2002. Between Wave-and Tide-Dominated Coasts: the Middle Ground Revisited. Journal of Coastal Research SI 36:8-15.

Atwater BF. 1979. Ancient processes at the site of southern San Francisco Bay: movement of the crust and changes in sea level. In: Conomos TJ, editor. San Francisco Bay: the urbanized estuary. Menlo Park, CA: U.S. Geological Survey Open File Report 76-389.

Atwater BF, Conrad SG, Dowden JN, Hedel CW, MacDonald RL, Savage W. 1979. History, Landforms, and Vegetation of the Estuary's Tidal Marshes. In: Conomos TJ, editor. San Francisco Bay: The Urbanized Estuary. San Francisco, CA: Pacific Division, American Association for the Advancement of Science. p 347-385.

Atwater BF, Hedel CW, Helley EJ. 1977. Late Quaternary depositional history, Holocene sea-level changes, and vertical crustal movement in southern San Francisco Bay, CA. USGS Professional Paper 1014. 15 pp. p.

Buchanan P, Ganju N. 2003. Summary of suspended-sediment concentration data, San Francisco Bay, California, water year 2001. USGS Report 03-312:47 pp p.

Buchanan P, Ganju N. 2004. Summary of suspended-sediment concentration data, San Francisco Bay, California, water year 2002. USGS Report 2004-1219.:45 pp p.

Buchanan PA. 2003. Specific-conductance, water-temperature, and water-level data, San Francisco Bay, California, water years 2001-2002. Interagency Ecological Program Newsletter 16(4):25-30.

Buchanan PA, Ganju NK. 2002. Summary of suspended-sediment concentration data, San Francisco Bay, California, water year 2000. U.S. Geological Survey. Report nr 02-146.

Buchanan PA, Ruhl CA. 2001. Summary of suspended-solids concentration data, San Francisco Bay, California, water year 1999. U.S. Geological Survey. Report nr 01-100. 56 p.

Burgmann R, Hilley G, Ferretti A, Novali F. 2006. Resolving vertical tectonics in the San Francisco Bay area from permanent scatterer InSAR and GPS analysis. Geology 34:221-224.

Collins JN, Grossinger RM. 2004. Synthesis of scientific knowledge concerning estuarine landscapes and related habitats of the South Bay Ecosystem. Oakland, CA: San Francisco Estuary Institute. 91 p.

Conomos TJ. 1979. San Francisco Bay: The Urbanized Estuary. Conomos TJ, Leviton AE, Berson M, editors. San Francisco, CA: Pacific Division of the American Association for the Advancement of Science c/o California Academy of Sciences.

Cooper J. 2002. The role of extreme floods in estuary-coastal behavior: contrasts between river- and tide-dominated microtidal estuaries. Sedimentary Geology 150(2002):123-137.

Corwin R. 1999. Section 4. Tidal Sedimentation - SP Surveys. Sonoma Baylands Wetland Demonstration Project Tidal Sedimentation from Resistivity Measurements Period Ending December 31, 1999. Sonoma Baylands Monitoring Report.

D'Alpaos A, Lanzoni S, Marani M, Fagherazzi S, Rinaldo A. 2005. Tidal network ontogeny: Channel initiation and early development. Journal of Geophysical Research 110(F02001).

Dyer K. 1998. The topology of intertidal mudflats. In: K.S. Black DMPaAC, editor. Sedimentary Processes in the Intertidal Zone. No. 139 ed: The Geological Society.

Eisma D, Dijkema KS. 1997. The influence of salt marsh vegetation on sedimentation. In: Eisma D, editor. Intertidal Deposits. Boca Raton, Florida: CRC Press. p 403-414.

EMPHASYS Consortium. 2000. A Guide to Prediction of Morphological Change within Estuarine Systems, Version 1B. MAFF. Report nr TR 114.

Foxgrover AC, Higgins SA, Ingraca MK, Jaffe BE, Smith RE. 2004. Deposition, erosion, and bathymetric change in South San Francisco Bay: 1858-1983.: U.S. Geologic Survey Open-File Report 2004-1192. 25 p.

Friedrichs CT, Aubrey DO. 1996. Uniform bottom shear stress and equilibrium hypsometry of intertidal flats. In: Pattiaratchi C, editor. Mixing in Estuaries and Coastal Seas: American Geophyscial Union. p 405-429.

Gilbert GK. 1917. Hydraulic mining debris in the Sierra Nevada USGS Professional Paper 105. U.S. Geologic Survey. 154 p.

Goals Project. 1999. Baylands Ecosystem Habitat Goals. A report of habitat recommendations prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. First Reprint. San Francisco, CA/Oakland, CA: U.S. Environmental Protection Agency/San Francisco Bay Regional Water Quality Control Board. 209 p.

Healy T, Hull J, Hume T. 2001. Dispersal of muddy dredged material on broad inter-tidal flats in a fetch-limited environment. Shore & Beach 69(1):15-22.

IPCC. 2001. Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Houghton JT, Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, C.A. Johnson (eds.), editor. Cambridge: Cambridge University Press. 881 p.

Jaffe, B. E. and A. C. Foxgrover (2006a). Sediment deposition and erosion in South San Francisco Bay, California from 1956 to 2005, U.S. Geological Survey Open-File Report 2006-1287: 20.

Jaffe, B. E. and A. C. Foxgrover (2006b). A History of intertidal flat area in South San Francisco Bay, California: 1858 to 2005, U.S. Geological Survey Open-File Report 2006-1262: 28.

Kirby R. 2000. Practical implications of tidal flat shape. Continental Shelf Research 20:1061-1077.

Krone RB. 1987. A Method for Simulating Historic Marsh Elevations. Presented at ASCE Specialty Conference, Coastal Sediments '87 New Orleans, LA:12-14.

Lawrence D, Allen J, Havelock G. 2004. Salt Marsh Morphodynamics: an Investigation of Tidal Flows and Marsh Channel Equilibrium. Journal of Coastal Research 20(1):301-316.

Lionberger MA, Schoellhamer DH, Oram J, May C. A tidally averaged sediment-transport model of San Francisco Bay, California. Proceedings of the Joint Federal Interagency Conference 2006; 2006 April 2-6; Reno, NV. p 8.

Long A, Scaife, RG, Edwards, RJ. 2000. Stratigraphic architecture, relative sea-level and models of estuary development in southern England: new data from Southampton Water. In: Allen KPaJ, editor. Coastal and estuarine environments: sedimentology, geomorphology and geoarchaeology: Geological Society of London. p 253 - 280.

McKee L, Leatherbarrow J, Davis J, Pearce S. 2002. A review of urban runoff processes in the San Francisco Bay Area: Existing knowledge, conceptual models, and monitoring recommendations. Oakland, CA: San Francisco Estuary Institute.

Meehl G, Washington W, Collins W, Arblaster J, Hu A, Buja L, Strand W. 2005. How much more global warming and sea level rise. Science 307:1769-1772.

NOAA Science Panel II. 2002. General comments on the URS April and July, 2002 Draft Technical and Scientific Studies.

Orr MK, Crooks S, Williams PB. 2003. Will Restored Tidal Marshes Be Sustainable? San Francisco Estuary and Watershed Science 1(1):Article 5.

Patrick WH, Delaune RD. 1990. Subsidence, Accretion, and sea level rise in south San Francisco Bay marshes. Limnol Oceanogr 35(6):1389-1395.

Pestrong R. 1965. The development of drainage patterns on tidal marshes. Stanford University Publications in Geological Sciences Stanford University, Palo Alto CA.

Pethick J. 1984. An introduction to coastal geomorphology: Edwin Arnold, London.

Pethick J. 1996. The Blackwater estuary. II. Geomorphological trends 1978 to 1994: Cambridge Coastal Research Unit.

Pethick J. 2001. Coastal management and sea-level rise. Catena 42(2001):307-322.

Pethick J, Crooks S. 2000. Development of a coastal vulnerability index: a geomorphological perspective. Environmental Conservation 27(4):359-367.

Pethick J, Lowe J. 1999. The Health of Estuaries - Indicators of Geomorphological Functioning of Estuaries. University of Newcastle report for English Nature.

Poland JF, Ireland RL. 1988. Land Subsidence in the Santa Clara Valley, California, as of 1982. U.S. Geological Survey. Report nr 497-F. 61 p.

Porterfield G. 1980. Sediment transport of streams tributary to San Francisco, San Pablo and Suisun Bays, CA, 1909, 1966, 1980. Report nr USGS Water Resources Investigation 80-64.

Pritchard D, Hogg A. 2003. Cross-shore sediment transport and the equilibrium morphology of mudflats under tidal currents. Journal of Geophysical Research 108(C10).

Pritchard D, Hogg AJ, Roberts W. 2002. Morphological modelling of intertidal mudflats: the role of cross-shore tidal currents. 22:1887-1895.

PWA. 1995. Design Guidelines for Tidal Channels in Coastal Wetlands. Prepared for U.S. Army Corps of Engineers Waterways Experiment Station.

PWA. 2004. Design Guidelines for Tidal Wetland Restoration in San Francisco Bay Version 1.0. San Francisco, CA: in preparation for The Bay Institute.

PWA, H. T. Harvey & Associates, EDAW, Brown and Caldwell. 2005. Hydrodynamics and Sediment Dynamics Existing Conditions Report. San Francisco, CA.: Prepared for: California State Coastal Conservancy, U.S. Fish and Wildlife Service, California Department of Fish and Game.

PWA, H. T. Harvey & Associates, EDAW, Brown and Caldwell. 2006. Final Alternatives Report. San Francisco, CA.: Prepared for: California State Coastal Conservancy, U.S. Fish and Wildlife Service, California Department of Fish and Game.

Reed D. 1990. The impact of sea-level rise on coastal salt marshes. Progress in Physical Geography 14:465 - 481.

Roberts W, Le Hir P, Whitehouse RJS. 2000. Investigation using simple mathematical models of the effect of tidal currents and waves on the profile shape of intertidal mudflats. Continental Shelf Research 20(2000):1079-1097.

San Francisco Estuary Institute. 1998. San Francisco Estuary Institute, EcoAtlas, http://www.sfei.org/ecoatlas/. Oakland, CA: SFEI.

Schmidt DA, Burgmann R. 2003. Time-dependent uplift and subsidence in the Santa Clara Valley, from a large interferometric synthetic aperture radar data set. Journal of Geophysical Research - Solid Earth 108:2416.

Schoelhamer DH, Orlando J, Wright SA, Freeman LA. Sediment supply and demand (abstract). South Bay Science Symposium.; 2006 June 6; San Jose, CA.

Schoellhamer D. 1996. Factors affecting suspended-solids concentrations in South San Francisco Bay, California. Journal of Geophysical Research - Oceans 101(C5):12087-12095.

Schoellhamer D, Lacy J, Ganju N, Shellenbarger G, Lionberger M. 2005. Draft Science Synthesis. Issue 2. Sediment management: Creating desired habitat while preserving existing habitat.

Shennan I, Couilthard, T, Flather, R, Horton, B, Macklin, M, Rees, J, Wright, M. 2003. Integration of shelf evolution and river basin models to simulate Holocene sediment dynamics of the Humber Estuary during periods of sea-level change and variations in catchment sediment supply. The Science of the Total Environment 314-316(2003):737-754.

Trulio LA, Clark D. 2005. South Bay Salt Pond Restoration Project Draft Adaptive Management Plan. Prepared for: California State Coastal Conservancy, U.S. Fish and Wildlife Service, California Department of Fish and Game.

Uncles RJ, Peterson DH. 1995. A computer model of long-term salinity in San Francisco Bay: sensitivity to mixing and inflows. Environmental International 21(5):647-656.

Walters RA, Cheng RT, Conomos TJ. 1985. Time scales of circulation and mixing processes of San Francisco Bay waters. Hydrobiologia 129: p13-36.

Watson EB. 2004. Changing elevation, accretion, and tidal marsh plant assemblages in South San Francisco Bay tidal marsh. Estuaries 27(4):684-698.

Wigley T. 2005. The climate change commitment. Science 307:1766-1769.

Wilcock P, Iverson R. 2003. Prediction in Geomorphology. In: Wilcock P, Iverson, RM, editor. Prediction in Geomorphology. Washington D.C.: American Geophysical Union.

Williams P, Vorster P. 1987. Changes in short duration spring flow peaks into San Francisco Bay due to upstream water development. PWA Report 412-3.

Williams PB, Faber P. 2001. Salt Marsh Restoration in San Francisco Bay. Journal of Coastal Research(Special Issue 27):203-211.

Williams PB, Orr MK, Garrity NJ. 2002. Hydraulic geometry: A geomorphic design tool for tidal marsh channel evolution in wetland restoration projects. Restoration Ecology 10(3):577-590.

WL | Delft Hydraulics. 2003. Delft3D-FLOW, Simulation of multi-dimensional hydrodynamic flows and transport phenomena, including sediments. Delft, NL.

Woodroffe C. 2002. Coasts: Form, process and evolution: Cambridge University Press.

Wright SA, Schoellhamer DH. 2004. Trends in the Sediment Yield of the Sacramento River, California, 1957 - 2001. San Francisco Estuary and Watershed Science 2(2).

# 10. LIST OF PREPARERS

The following Team members assisted in preparation of this document:

Philip Williams, Principal, Ph.D., P.E., PWA
David Brew, Senior Associate, Ph.D., PWA
Steve Crooks, Senior Associate, Ph.D.
Jeremy Lowe, Associate Principal, B.A., PWA
Gaurav Misra, Hydrologist, M.S., PWA
Nick Garrity, Associate, M.S., PWA
Julie Stephenson, Hydrologist, M.A., PWA
Kris May, Senior Associate, Ph.D., PWA

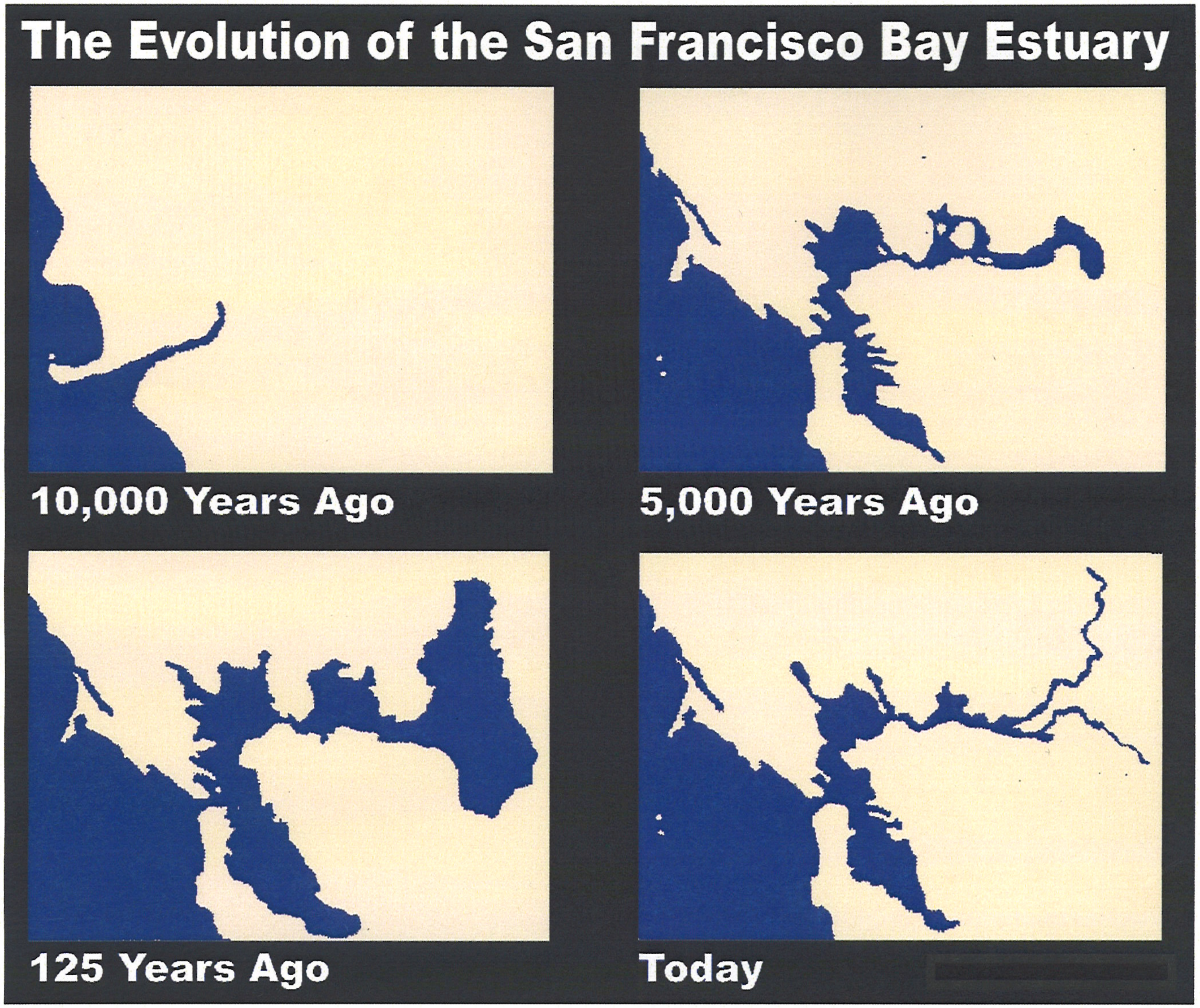
Source files for this report are located at PWA:

P:\Projects\1750_South_Bay_Salt_Ponds\Task03d_Landscape_Assessment\GeoMorphAssessRpt-PDFsOctober26-06\SBSP-GeoMorphAssess-Final-v12.doc

<This page intentionally left blank>

# FIGURES

<This page intentionally left blank>



*Source: Atwater (1979)*

*figure 1*

*South Bay Salt Pond Restoration Project*

**Holocene Evolution of San Francisco Bay**

PWA Ref SBSP/1750.03d/Geomorphic Assessment/Fig1 holocene

PWA

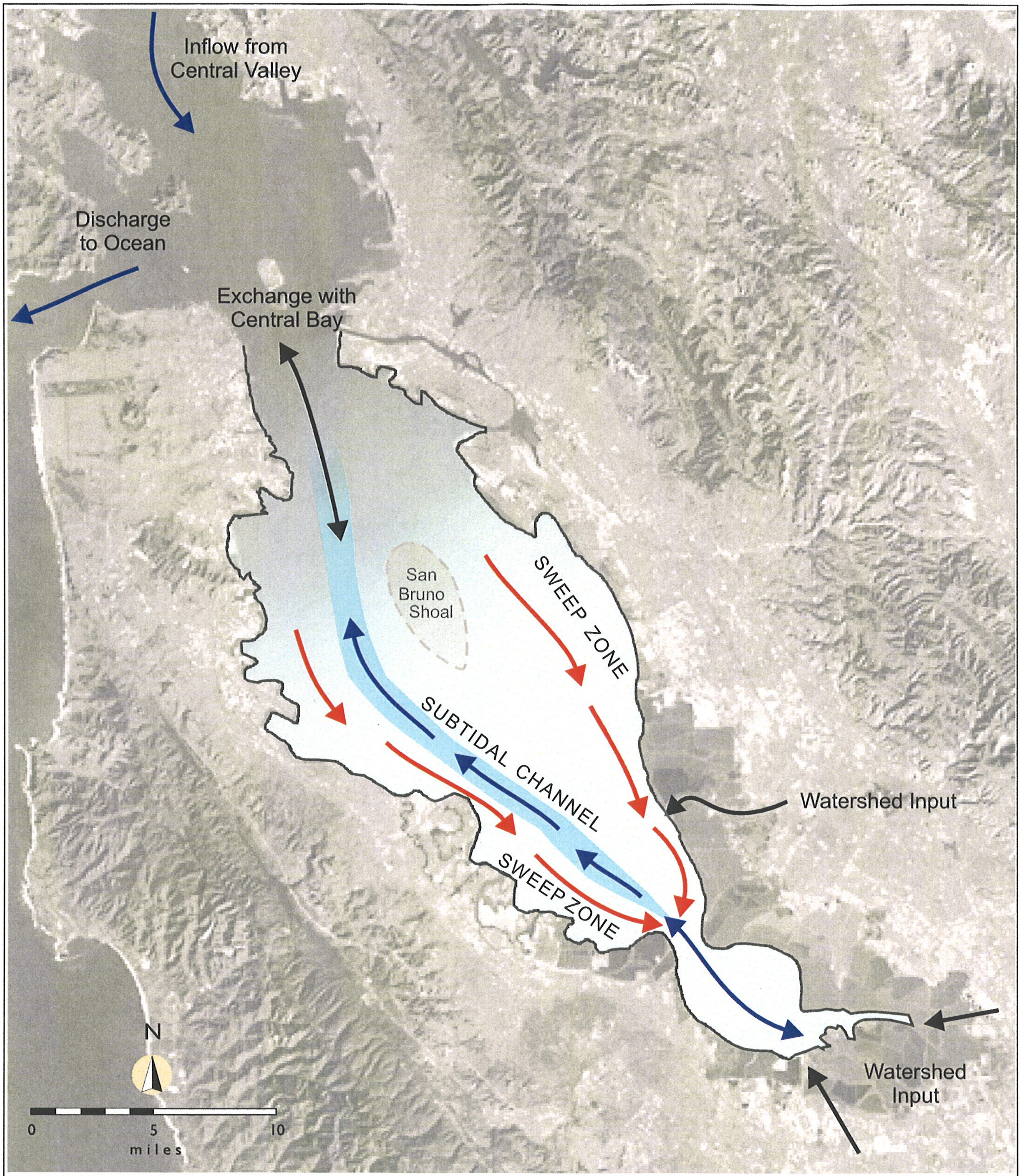


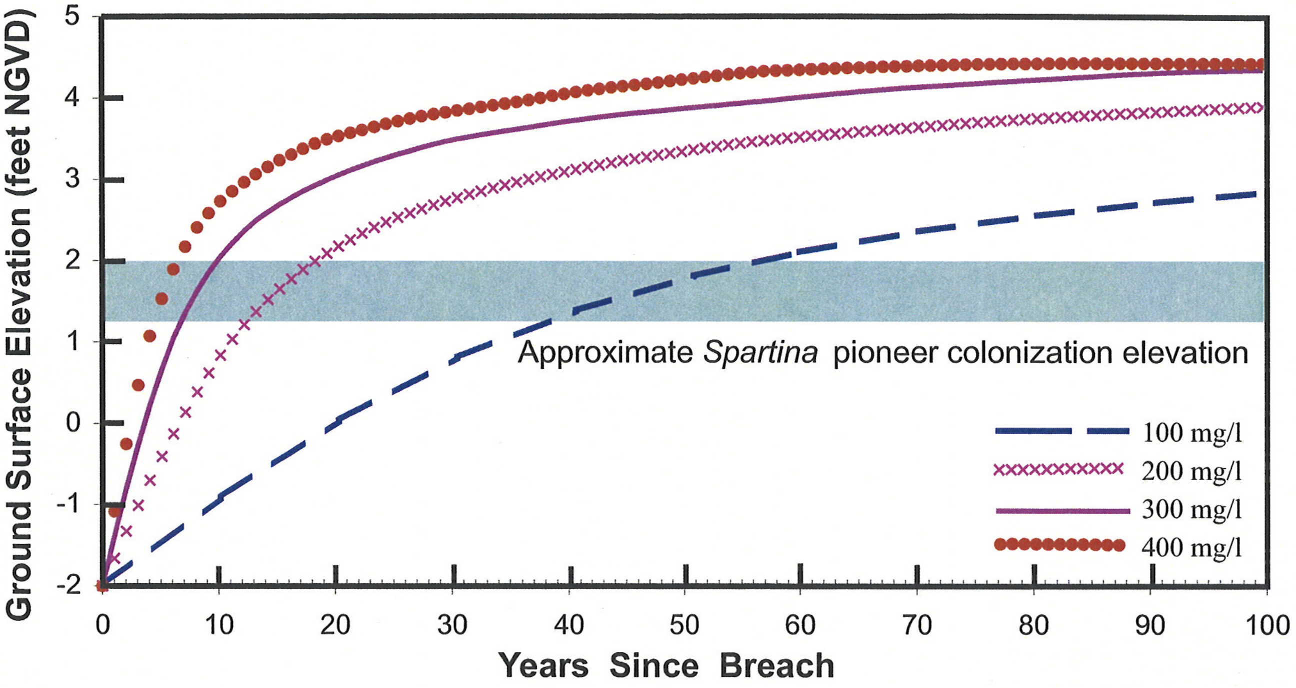
*figure* 2

*South Bay Salt Pond Restoration Project*

## Conceptual Model of Net Sediment Transport Patterns for South Bay

PWA Ref SBSP/1750.03d/Geomorphic Assessment/Fig2_TranspPattern.cdr

PWA



Shaded bar identifies the approximate *Spartina foliosa* colonization elevation. Prediction is based on tides at the Presidio, no sea level rise, and 550 kg/m$^3$ dry density of inorganics, typical for San Francisco Bay.

*figure* 3

*South Bay Salt Pond Restoration Project*

## Conceptual Model of Marsh Plain Evolution

*Source: Williams and Orr (2002)*

PWA Ref SBSP/1750.03d/Geomorphic Assessment/ Fig3_EfSuspSed.cdr

PWA

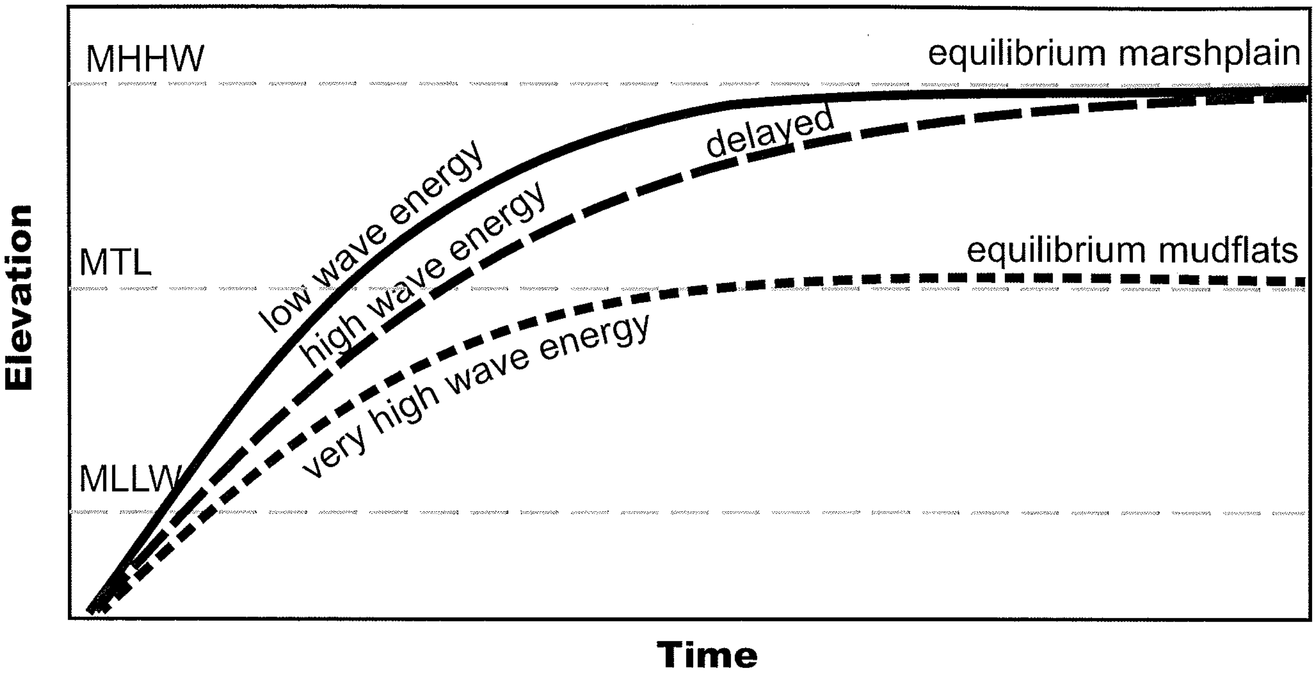


*figure* 4

*South Bay Salt Pond Restoration Project*

**Conceptual Effect of Wind Waves on Tidal Marsh Evolution**

*Source: Williams and Orr (2002)*

PWA Ref SBSP/1750.03d/Geomorphic Assessment/ Fig4_EfWW.cdr

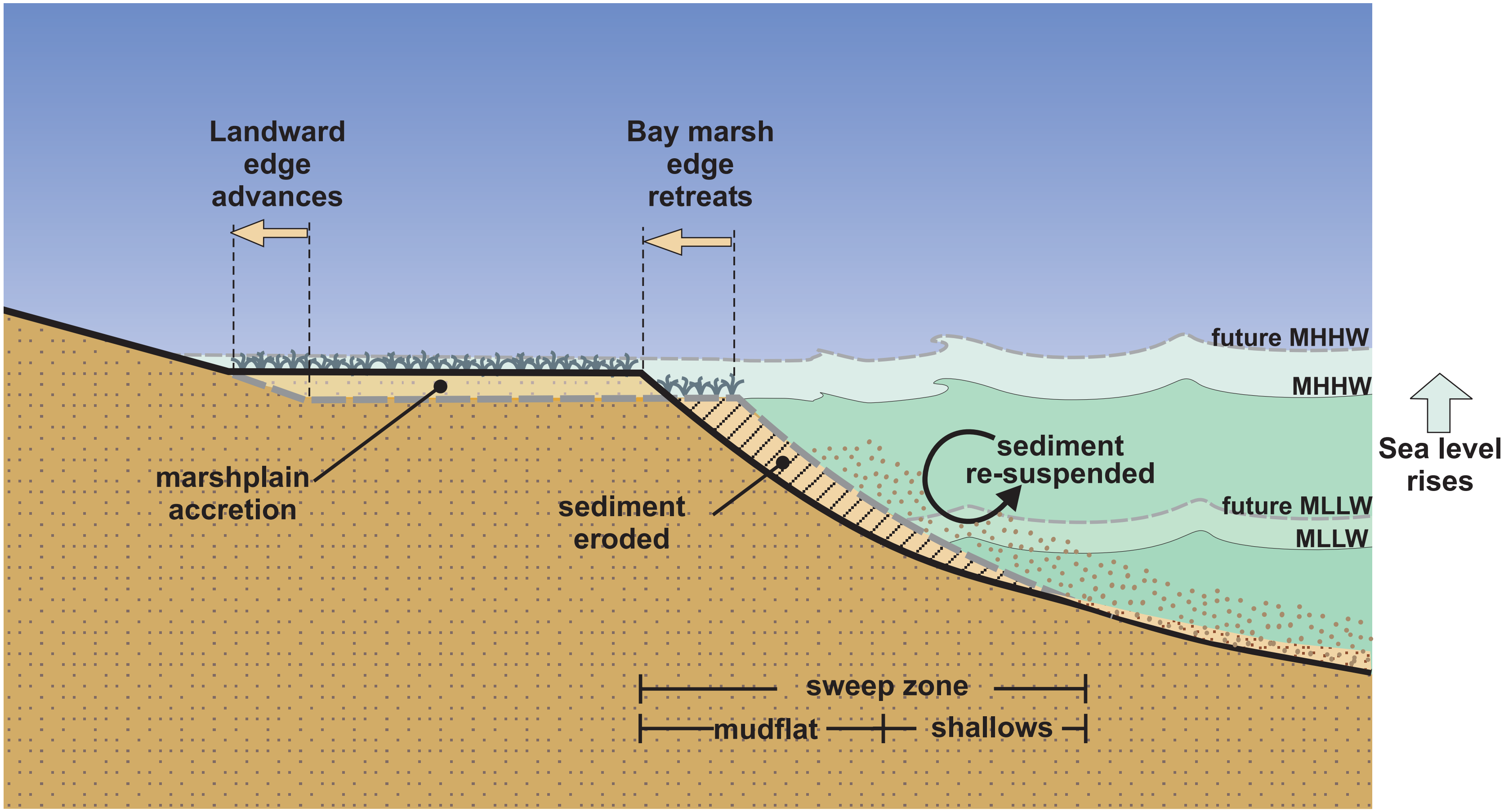


*figure* 5

*South Bay Salt Pond Restoration Project*

## Conceptual Model of Evolution of Sweep Zone and Shoreline in Transgressive Estuary

PWA Ref SBSP/1750.03d/Geomorphic Assessment/ Fig5_TrnsgrsnBySeaLevelRise.cdr

PWA

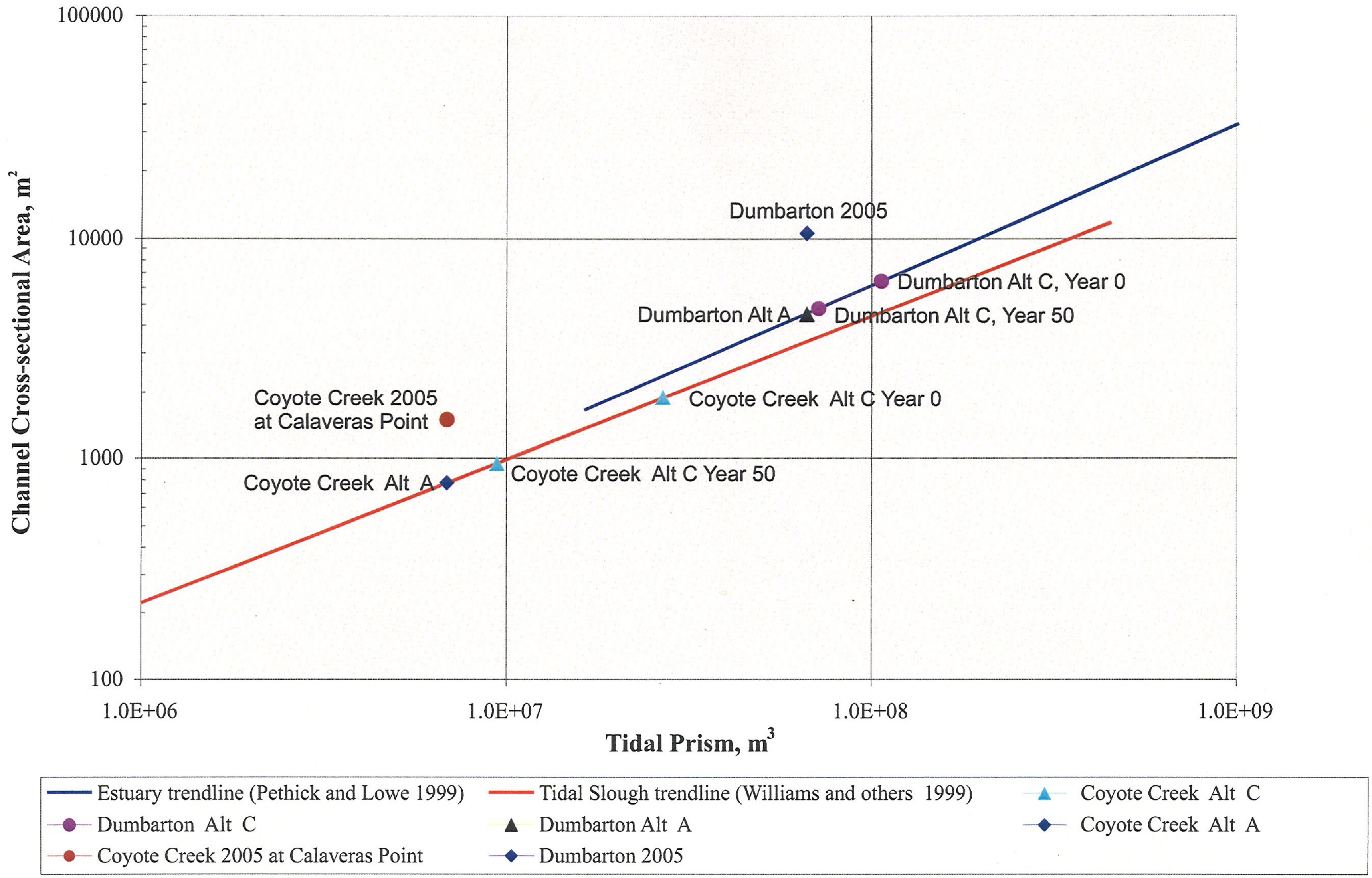


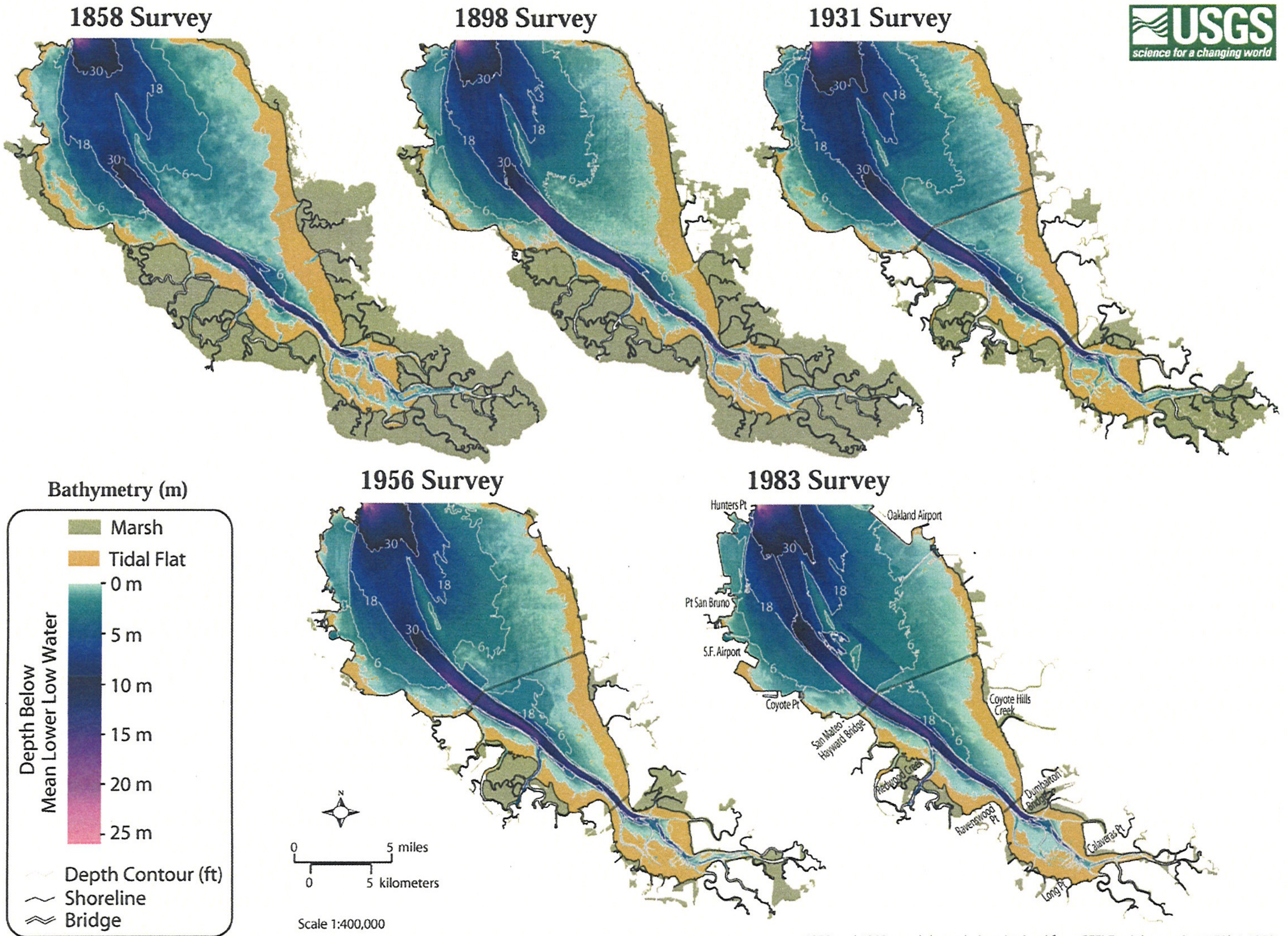
*figure 6*

*South Bay Salt Pond Restoration Project*

**Hydraulic Geometry of Estuarine Subtidal and Marsh Slough Channels**

PWA Ref. SBSP/1750.03d/ Geomorphic Assessment/ Fig6_HydGeom.cdr

PWA



1858 and 1983 marsh boundaries obtained from SFEI EcoAtlas version 1.50b4, 1998.

*figure* 7

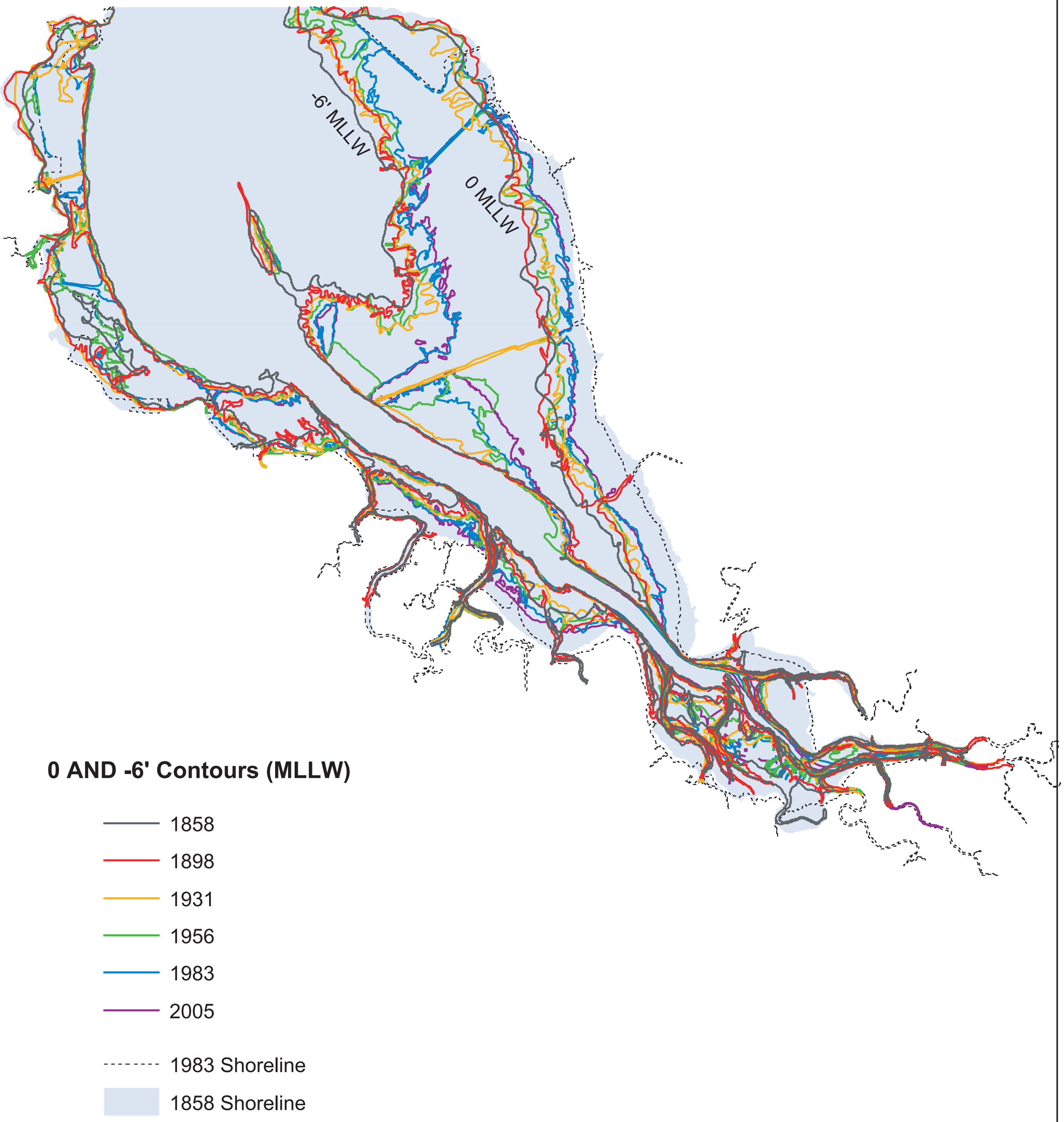
*South Bay Salt Pond Restoration Project*

## Historic Changes in Bathymetry of South Bay

*Source: Foxgrover and others (2004)*

PWA Ref. SBSP/1750.03d/ Geomorphic Assessment /Fig7_BathySB.cdr

PWA



Source: Jaffe and Foxgrover 2006-a

*figure* 8

*South Bay Salt Pond Restoration Project*

# Historic Changes in South Bay Bathymetric Contours

PWA Ref. SBSP/1750.03d/ Geomorphic Assessment / Fig8 SBBathy.ai

PWA

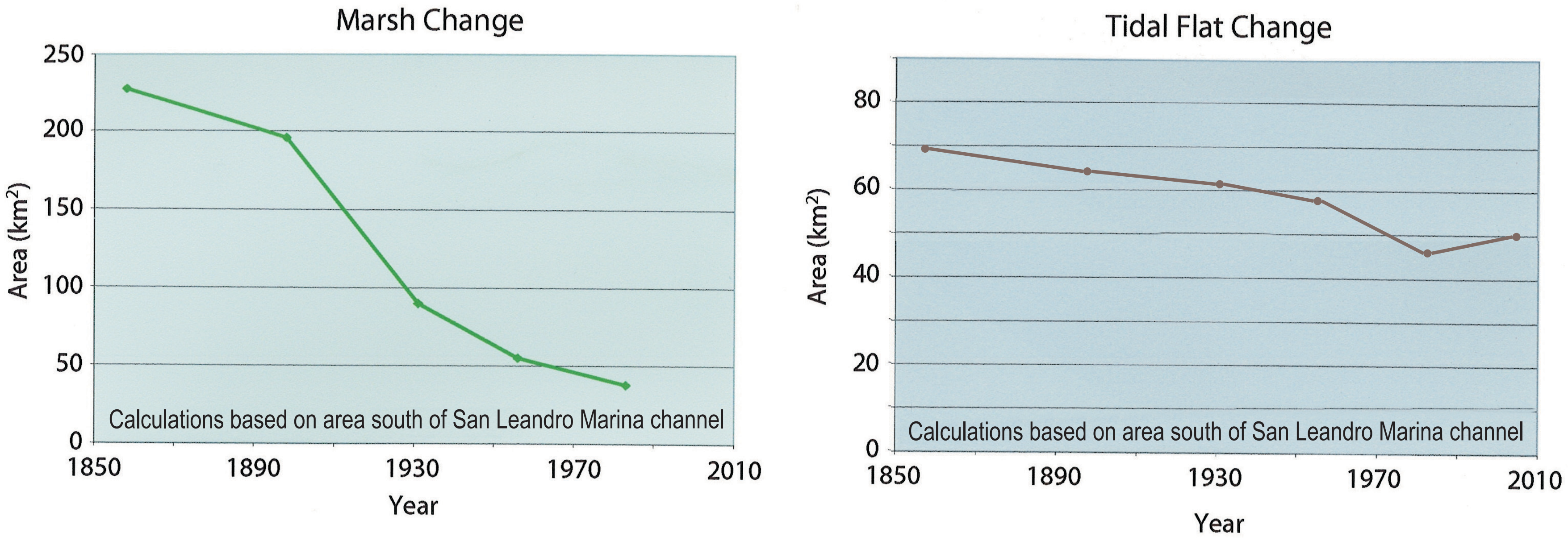


*figure* 9

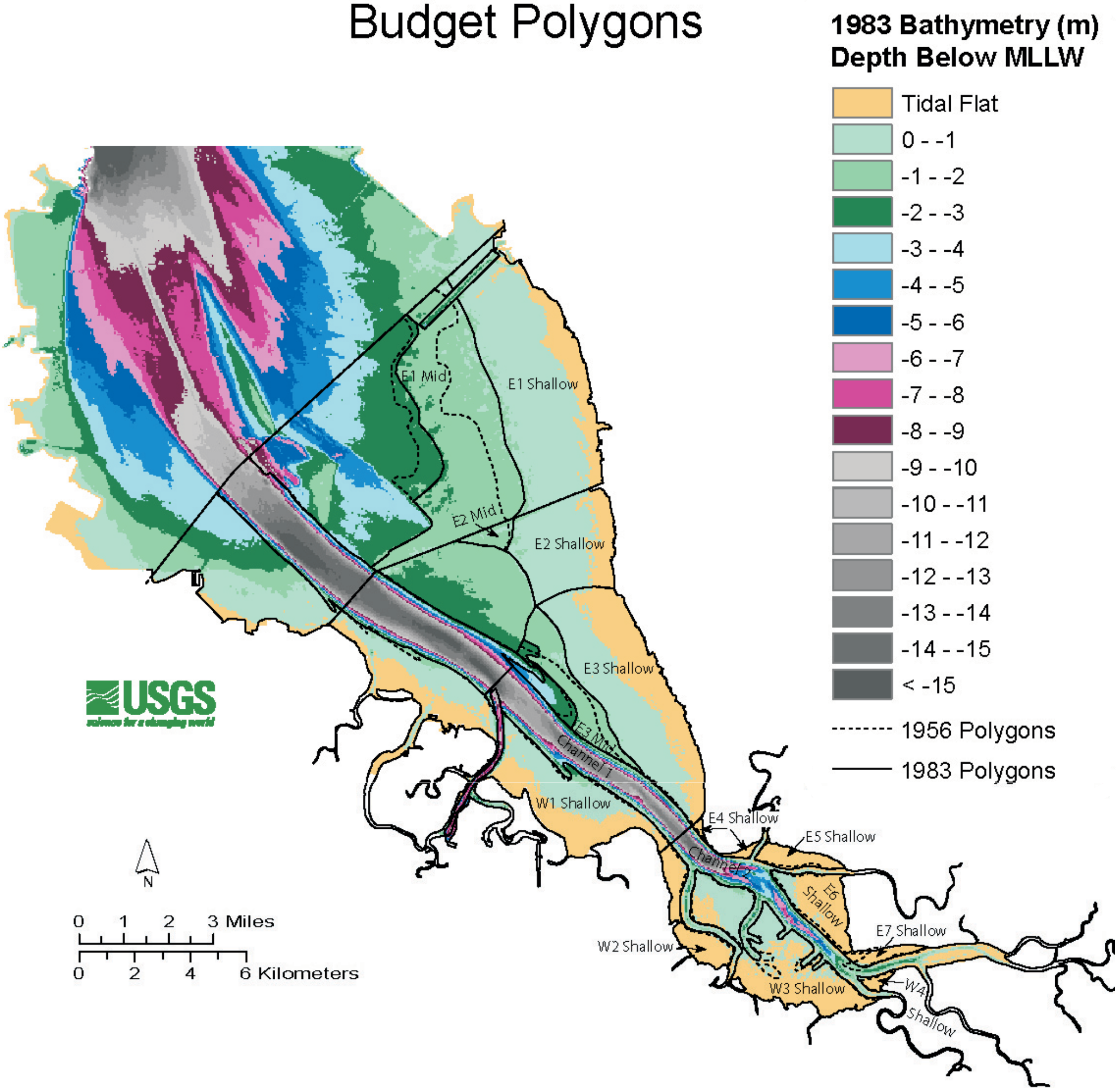
*South Bay Salt Pond Restoration Project*

## Historic Changes in Marsh and Mudflat Areas South of San Leandro Marina Channel

Source: Foxgrover and others 2004; Jaffe and Foxgrover 2006-b

PWA Ref. SBSP\1750.03d\ Geomorphic Assessment \ fig9 HistChgMF V2.cdr

# Regional Sediment Budget Polygons

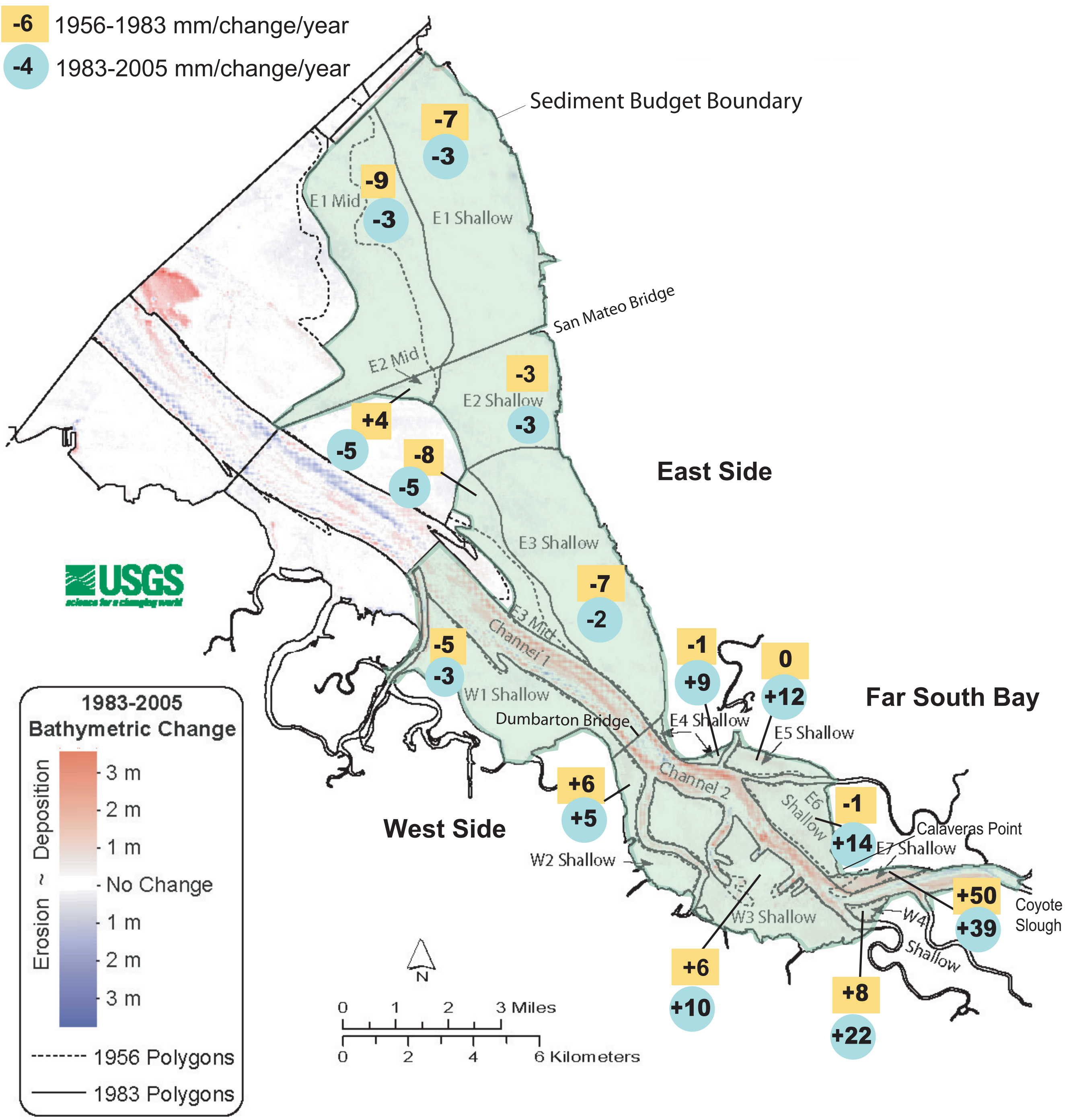


Source: Jaffe and Foxgrover 2006-a

*figure* 10

*South Bay Salt Pond Restoration Project*

**Identification of Sediment Budget Geomorphic Units**

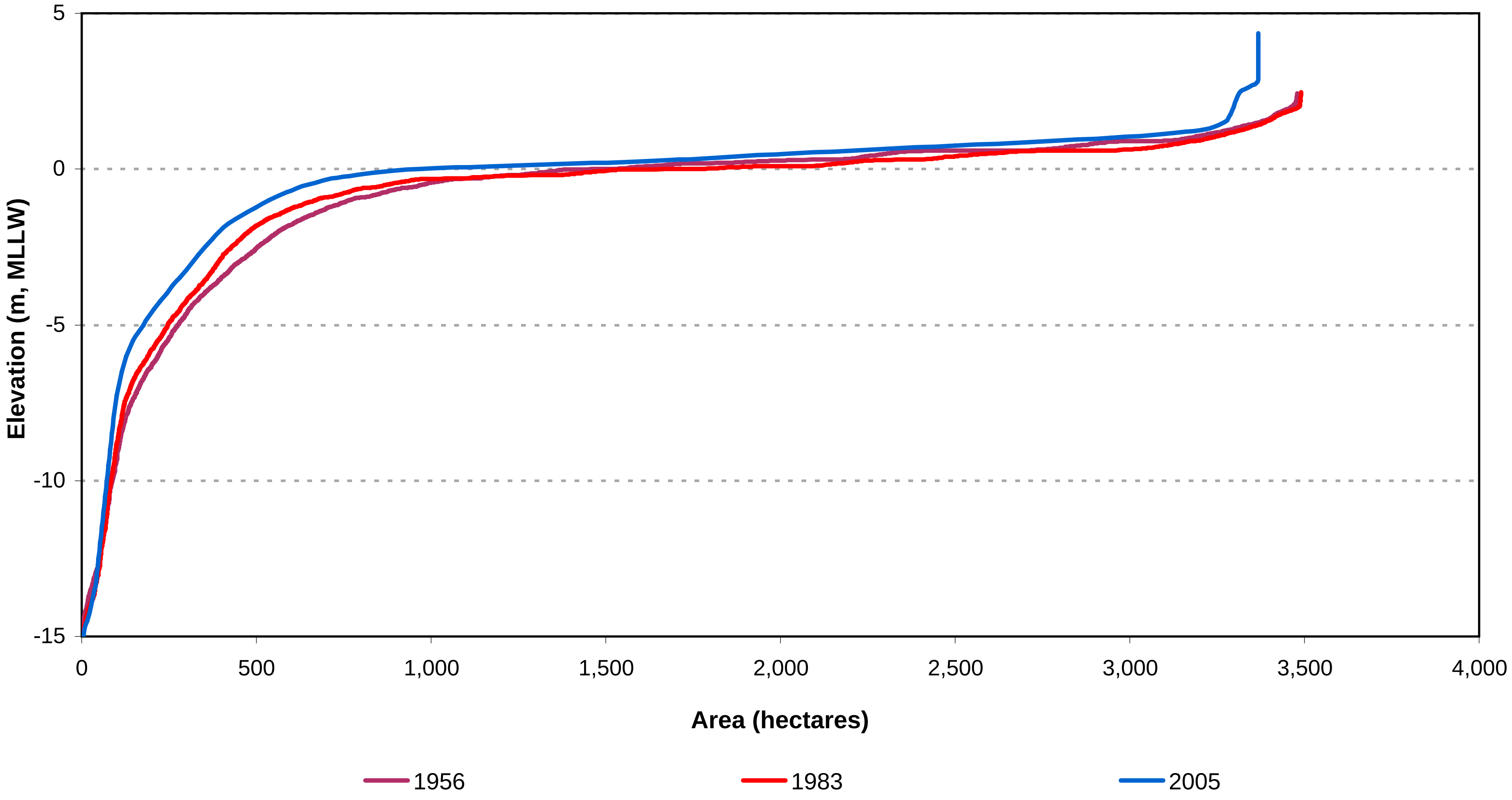


Source: Jaffe and Foxgrover 2006-a

*figure 11*

*South Bay Salt Pond Restoration Project*

## Comparison of Erosion / Accretion Rates 1956-1983 and 1983-2005



Notes: Hypsometry created from USGS bathymetry
Far South Bay = between Dumbarton Bridge and Coyote Creek extension

Source: Jaffe and Foxgrover 2006-a

*figure* 12

*South Bay Salt Pond Restoration Project*

**Comparison of Far South Bay Hypsometry: 1956, 1983 and 2005**

PWA Ref. SBSP/1750.03d/ Geomorphic Assessment

PWA

P:\Projects\1750_South_Bay_Salt_Ponds\Task03d_Landscape_Assessment\Geomorphic_Assessment_Figures\hypso_FSB_56_04_js.xls

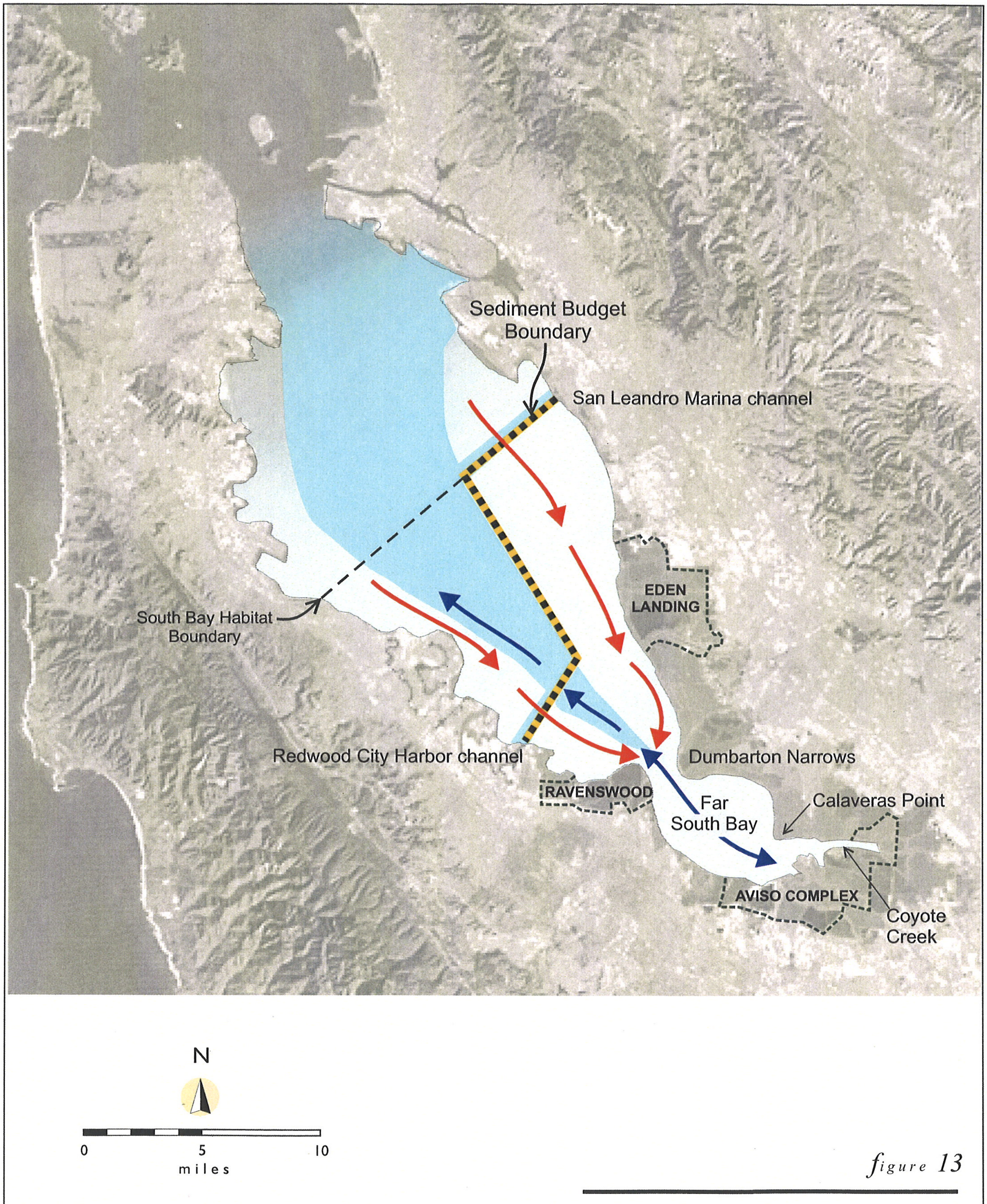


*figure 13*

*South Bay Salt Pond Restoration Project*

**Sediment Budget Boundary**

PWA Ref. SBSP/ 1750.03d/ Geomorphic lassessment / SedBudBoundary v3.cdr

PWA

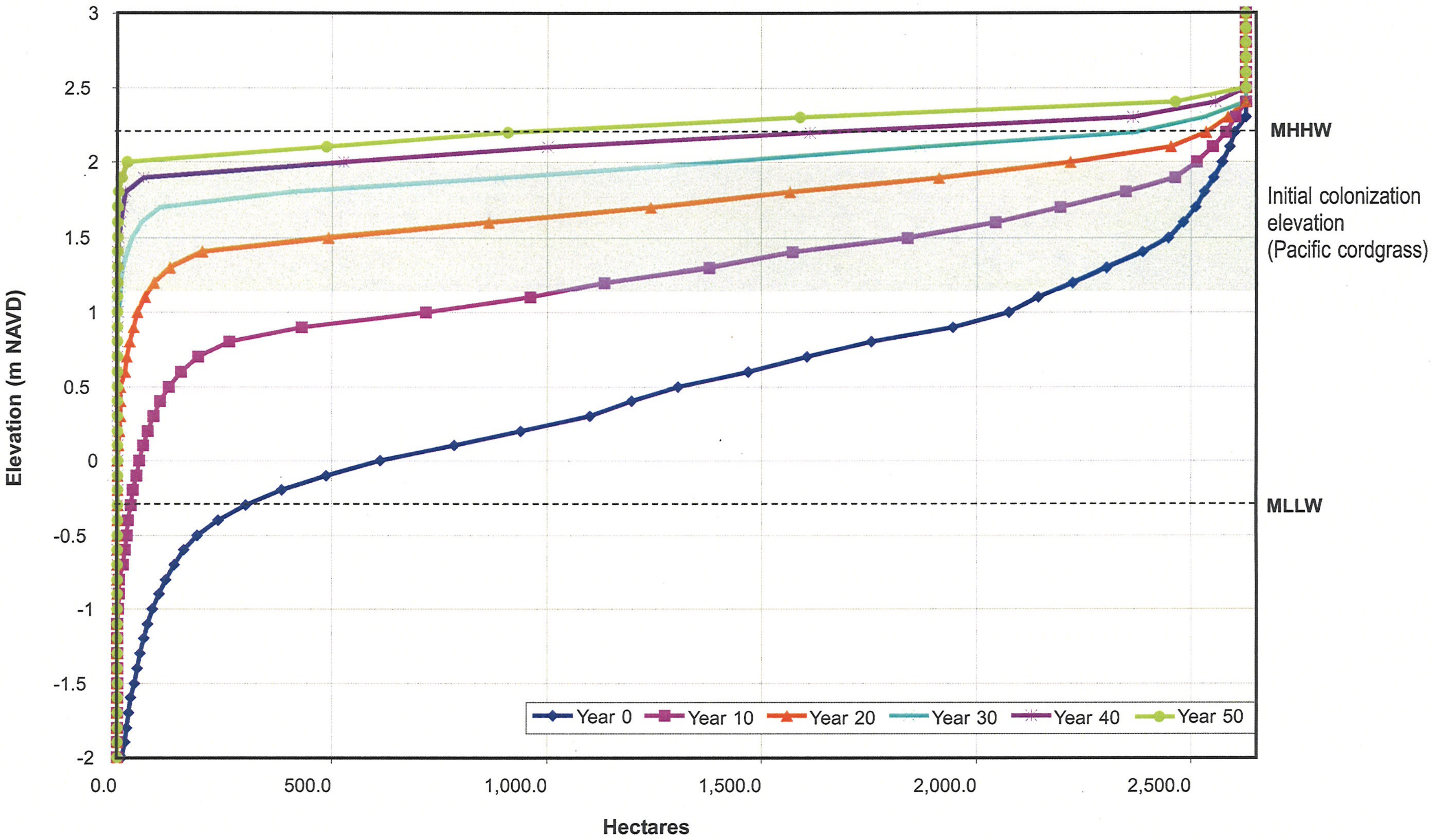


*figure 14*

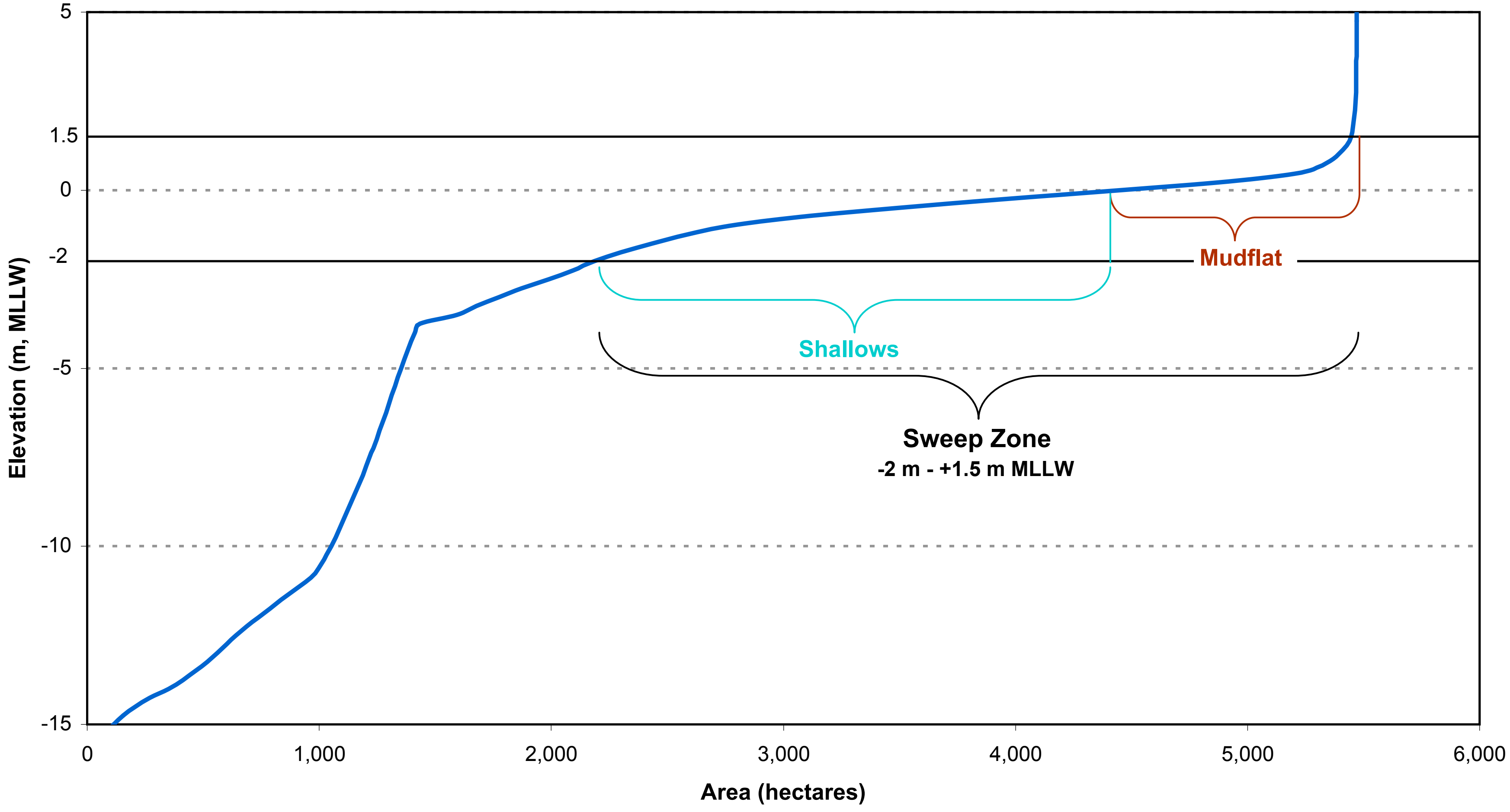
Notes:
Based on Alternative C evolution for the Alviso Complex
Based on an assumed constant SSC value of 200 mg/L
Based on an assumed constant relative sea-level rise of 3 mm/year

*South Bay Salt Pond Restoration Project*

## Evolution of Restored Pond Hypsometry

PWA Ref. SBSP/1750.03d/ Geomorphic Assessment / Figure14hypsmtycdr

PWA



Source: USGS Bathymetry, 2005

*figure* 15

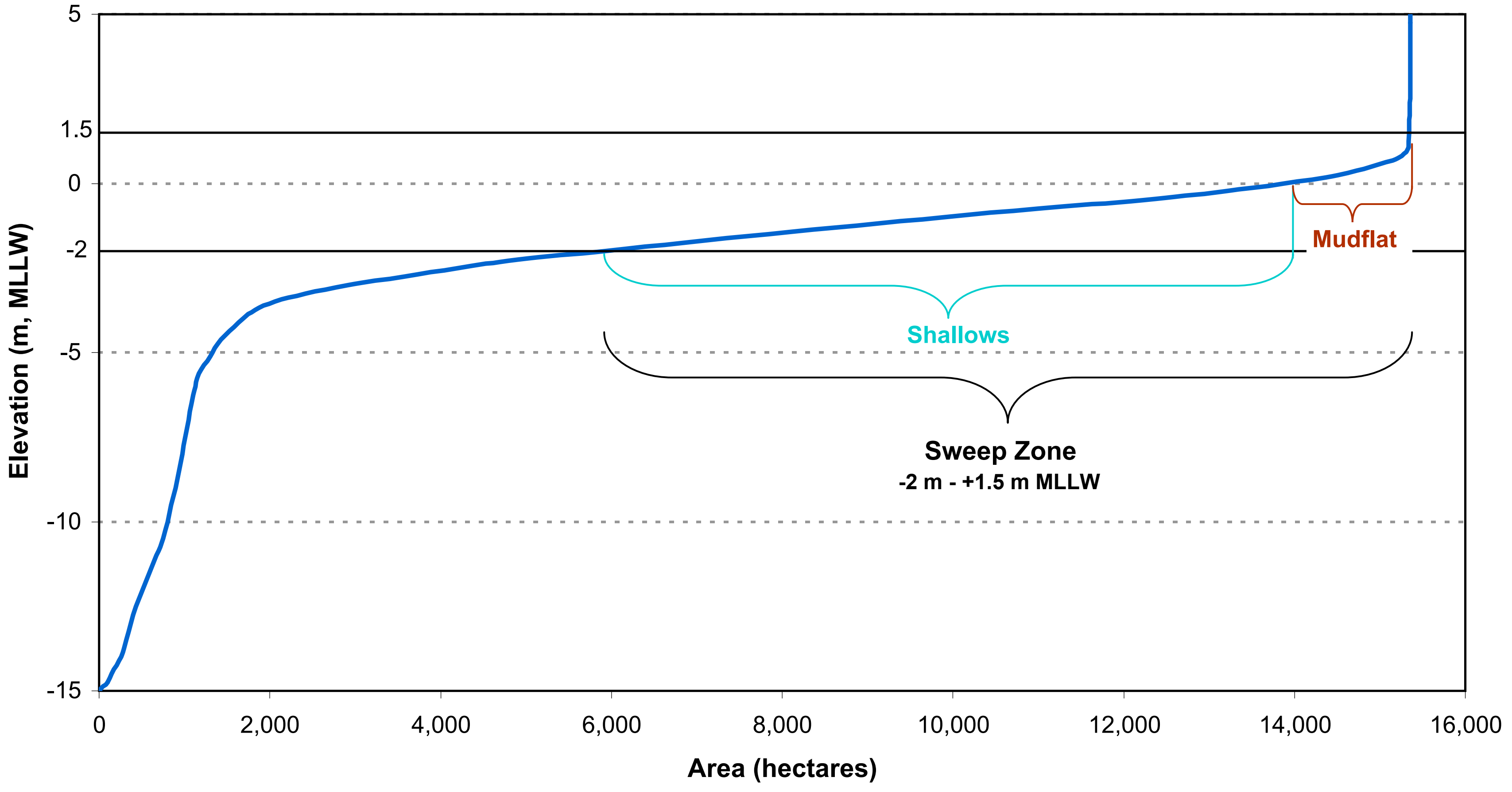
*South Bay Salt Pond Restoration Project*

**Hypsometry of South Bay Between Dumbarton Bridge and Coyote Point: West of Main Channel**

PWA Ref. SBSP/1750.03d/ Geomorphic Assessment

PWA

P:\Projects\1750_South_Bay_Salt_Ponds\Task03d_Landscape_Assessment\Geomorphic_Assessment_Figures\Hypso_N_of_DB.xls



Source: USGS Bathymetry, 2005

*figure* 16

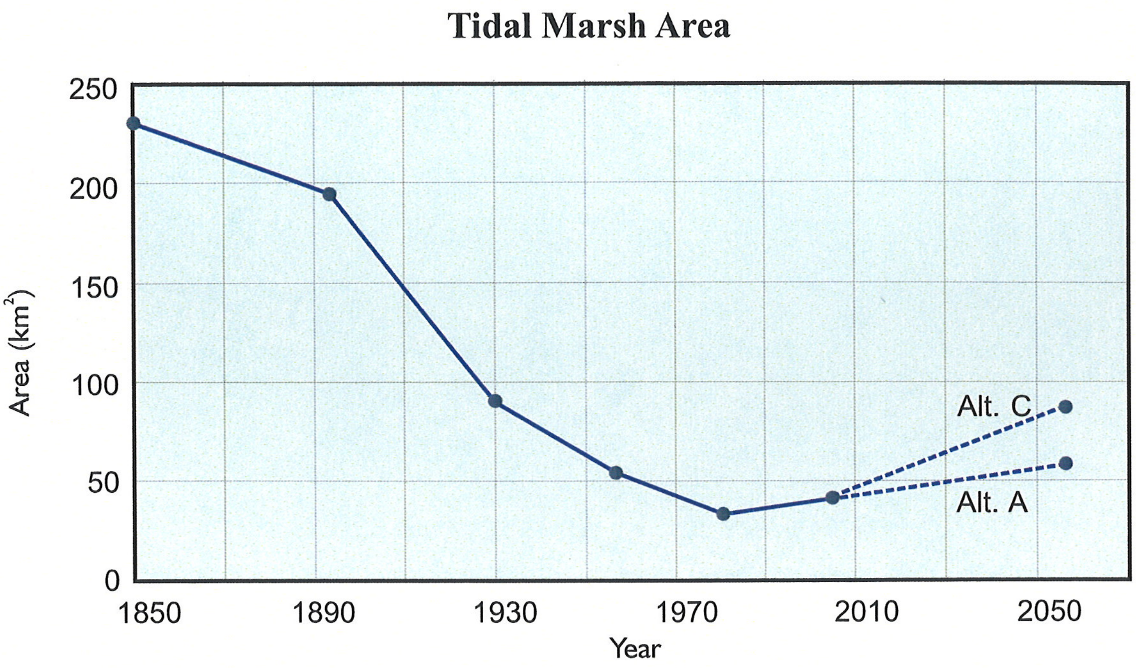
*South Bay Salt Pond Restoration Project*

**Hypsometry of South Bay Between Dumbarton Bridge and San Leandro Marina: East of Main Channel**

PWA Ref. SBSP/1750.03d/ Geomorphic Assessment

PWA

P:\Projects\1750_South_Bay_Salt_Ponds\Task03d_Landscape_Assessment\Geomorphic_Assessment_Figures\Hypso_N_of_DB.xls


Tidal Marsh Area

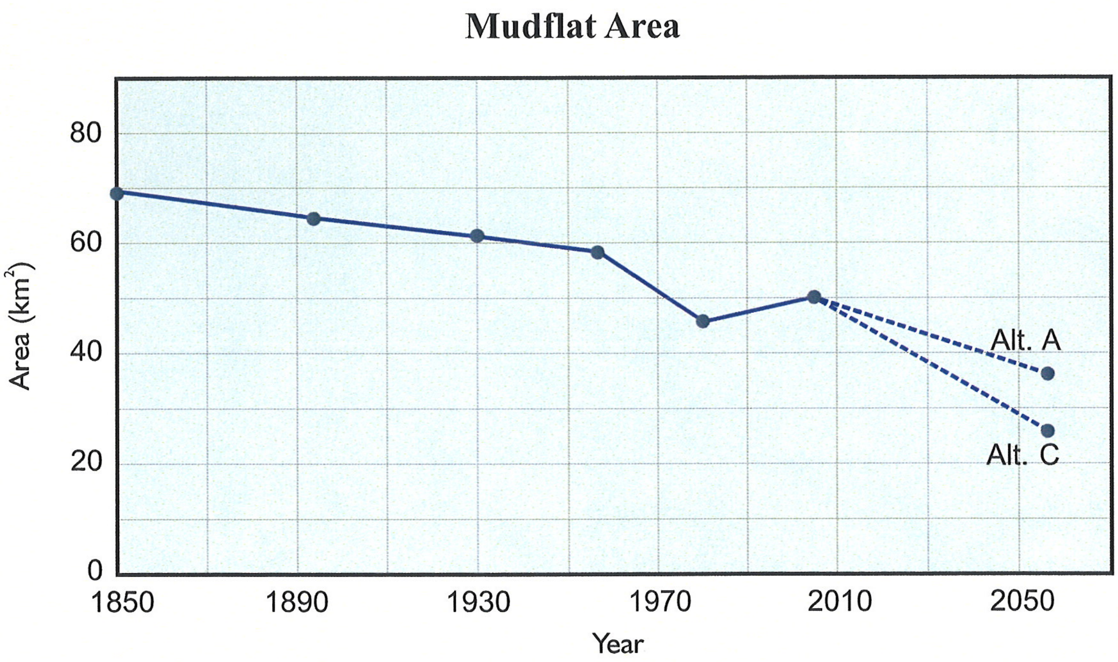

Mudflat Area

*figure* 17

*South Bay Salt Pond Restoration Project*

**Long Term Landscape Scale Intertidal Habitat Changes in South San Francisco Bay**

*Source for historic data prior to 2005:*
Foxgrover and others 2004

PWA Ref. SBSP/1750.03d/ Geomorphic Assessment / Fig17_HabChgs.cdr

PWA

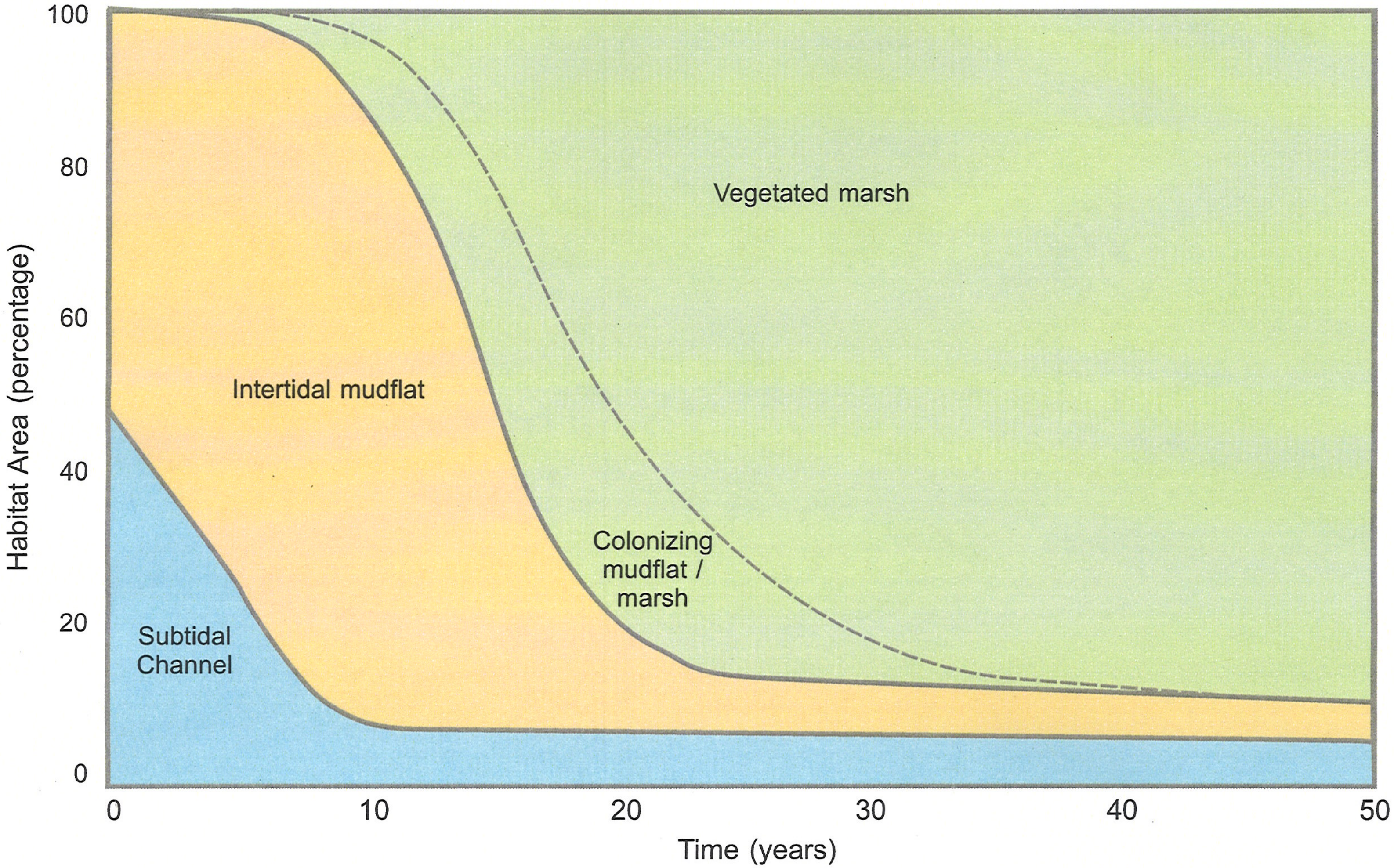


*figure 18*

*South Bay Salt Pond Restoration Project*

## Example of How Habitat Mix Changes in Restored Ponds

Note: Based on SSC of 200 mg/L

PWA Ref. SBSP/1750.03d/ Geomorphic Assessment / fig18 ExHabMix.cdr

PWA

# APPENDIX A.
# 1956-1983 AND 1983-2005 NET SEDIMENTATION RATES IN THE SOUTH BAY

<This page intentionally left blank>

| | 1956-1983[1] | | | 1983-2005[2] | | |
|---|---|---|---|---|---|---|
| | **Net Vol Chg (mcm)** | **Area (sq km)** | **Net Sed Rate (cm/yr)** | **Net Vol Chg (mcm)** | **Area (sq km)** | **Net Sed Rate (cm/yr)** |
| **E1 Shallow** | -7.37 | 36.91 | -0.74 | -2.09 | 28.24 | -0.34 |
| **E2 Shallow** | -1.02 | 11.35 | -0.33 | -0.82 | 11.39 | -0.33 |
| **E3 Shallow** | -4.39 | 23.92 | -0.68 | -1.32 | 21.28 | -0.28 |
| **E4 Shallow** | -0.01 | 0.47 | -0.08 | 0.11 | 0.50 | 1.04 |
| **E5 Shallow** | -0.01 | 1.57 | -0.02 | 0.58 | 1.77 | 1.48 |
| **E6 Shallow** | -0.12 | 4.05 | -0.11 | 1.70 | 4.50 | 1.72 |
| **E7 Shallow** | 1.31 | 0.97 | 5.00 | 1.12 | 1.08 | 4.73 |
| **W1 Shallow** | -1.52 | 11.11 | -0.51 | -0.97 | 11.50 | -0.39 |
| **W2 Shallow** | 0.52 | 3.22 | 0.60 | 0.50 | 3.55 | 0.65 |
| **W3 Shallow** | 1.85 | 11.95 | 0.57 | 3.41 | 12.65 | 1.22 |
| **W4 Shallow** | 0.08 | 0.35 | 0.85 | 0.28 | 0.47 | 2.69 |
| **E1 Mid** | -4.98 | 19.57 | -0.94 | -1.81 | 24.91 | -0.33 |
| **E2 Mid** | 0.09 | 1.00 | 0.33 | -0.15 | 1.13 | -0.59 |
| **E3 Mid** | -0.66 | 3.10 | -0.79 | -0.79 | 5.53 | -0.65 |
| **Channel 1** | 0 | 10.84 | 0.00 | 6.07 | 10.4 | 2.65 |
| **Channel 2** | 9.52 | 15.22 | 2.32 | 8.82 | 13.15 | 3.05 |

[1] 1956 - 1983 values include a subsidence correction (Foxgrover and others 2004) and a vertical datum adjustment of 4.9 cm based upon San Francisco tide station

[2] 1983 - 2005 values include a vertical datum adjustment of 1.8 cm based upon Alameda tide station

Source: Jaffe and Foxgrover, 2006-a.

<This page intentionally left blank>

# APPENDIX B.
# SEDIMENT DEMAND CALCULATIONS FOR EACH POND BY DECADE

<This page intentionally left blank>

### Table B-1. Pond sediment accumulation volumes in $m^3$ for Alternative C calculated for 200 ppm and 400 ppm using MARSH98.

| Alviso | Alternative C 400 ppm | Alternative C 200 ppm |
|---|---:|---:|
| *Years 0 - 10* | 39,719,953 | 20,707,220 |
| *Years 10 - 20* | 8,039,574 | 12,087,594 |
| *Years 20 - 30* | 1,752,041 | 6,862,320 |
| *Years 30 - 40* | 801,654 | 4,091,264 |
| *Years 40 - 50* | 788,419 | 2,705,875 |
| Total | 51,101,641 | 46,454,273 |

| Eden Landing | Alternative C 400 ppm | Alternative C 200 ppm |
|---|---:|---:|
| *Years 0 - 10* | 5,618,145 | 2,307,784 |
| *Years 10 - 20* | 2,289,730 | 1,731,184 |
| *Years 20 - 30* | 1,365,456 | 1,239,006 |
| *Years 30 - 40* | 880,437 | 865,127 |
| *Years 40 - 50* | 664,964 | 573,198 |
| Total | 10,818,732 | 6,716,300 |

| Ravenswood | Alternative C 400 ppm | Alternative C 200 ppm |
|---|---:|---:|
| *Years 0 - 10* | 1,942,823 | 703,311 |
| *Years 10 - 20* | 1,057,012 | 568,761 |
| *Years 20 - 30* | 613,822 | 379,033 |
| *Years 30 - 40* | 436,329 | 241,804 |
| *Years 40 - 50* | 335,625 | 5,662 |
| Total | 4,385,610 | 1,898,572 |

### Table B-2. Pond sediment demand volumes calculated for 400 ppm using 10% demand in year zero, 30% at year 10, 50% at year 20 (Alternative B), 70% at year 30 and 90% at year 40 (Alternative C).

| Alviso | Demand $Mm^3$ | Demand Mt | Demand x 85% Mt |
|---|---|---|---|
| Years 0 - 10 (10%) | 5.11 | 6.64 | 5.64 |
| Years 10 - 20 (20%) | 10.06 | 13.08 | 11.12 |
| Years 20 - 30 (20%) | 9.90 | 12.87 | 10.94 |
| Years 30 - 40 (20%) | 9.55 | 12.42 | 10.56 |
| Years 40 - 50 (20%) | 7.94 | 10.33 | 8.78 |
| Total Demand Alt C | 42.57 | 55.34 | 47.04 |
| Total Demand Alt B | 25.08 | 32.60 | 27.71 |
| Total Demand Alt A | 15.17 | 19.72 | 16.76 |

| Eden Landing | Demand $Mm^3$ | Demand Mt | Demand x 85% Mt |
|---|---|---|---|
| Years 0 - 10 (10%) | 1.08 | 1.41 | 1.20 |
| Years 10 - 20 (20%) | 2.03 | 2.64 | 2.24 |
| Years 20 - 30 (20%) | 1.85 | 2.41 | 2.05 |
| Years 30 - 40 (20%) | 1.58 | 2.06 | 1.75 |
| Years 40 - 50 (20%) | 1.12 | 1.46 | 1.24 |
| Total Demand Alt C | 7.67 | 9.97 | 8.48 |
| Total Demand Alt B | 4.97 | 6.46 | 5.49 |
| Total Demand Alt A | 3.11 | 4.05 | 3.44 |

| Ravenswood | Demand $Mm^3$ | Demand Mt | Demand x 85% Mt |
|---|---|---|---|
| Years 0 - 10 (10%) | 0.44 | 0.57 | 0.48 |
| Years 10 - 20 (20%) | 0.81 | 1.05 | 0.89 |
| Years 20 - 30 (20%) | 0.72 | 0.94 | 0.80 |
| Years 30 - 40 (20%) | 0.60 | 0.78 | 0.66 |
| Years 40 - 50 (20%) | 0.39 | 0.51 | 0.43 |
| Total Demand Alt C | 2.96 | 3.85 | 3.26 |
| Total Demand Alt B | 1.97 | 2.56 | 2.18 |
| Total Demand Alt A | 0.00 | 0.00 | 0.00 |

### Table B-3. Pond sediment demand volumes calculated for 200 ppm using 10% demand in year zero, 30% at year 10, 50% at year 20 (Alternative B), 70% at year 30 and 90% at year 40 (Alternative C).

| Alviso | Demand $Mm^3$ | Demand Mt | Demand x 85% Mt |
|---|---|---|---|
| Years 0 - 10 (10%) | 4.65 | 6.04 | 5.13 |
| Years 10 - 20 (20%) | 8.75 | 11.37 | 9.66 |
| Years 20 - 30 (20%) | 7.93 | 10.31 | 8.76 |
| Years 30 - 40 (20%) | 6.56 | 8.53 | 7.25 |
| Years 40 - 50 (20%) | 4.14 | 5.38 | 4.57 |
| Total Demand Alt C | 32.03 | 41.64 | 35.37 |
| Total Demand Alt B | 21.33 | 27.72 | 23.56 |
| Total Demand Alt A | 13.40 | 17.41 | 14.80 |

| Eden Landing | Demand $Mm^3$ | Demand Mt | Demand x 85% Mt |
|---|---|---|---|
| Years 0 - 10 (10%) | 0.67 | 0.87 | 0.74 |
| Years 10 - 20 (20%) | 1.23 | 1.60 | 1.36 |
| Years 20 - 30 (20%) | 1.06 | 1.37 | 1.16 |
| Years 30 - 40 (20%) | 0.81 | 1.05 | 0.89 |
| Years 40 - 50 (20%) | 0.46 | 0.60 | 0.51 |
| Total Demand Alt C | 4.23 | 5.49 | 4.66 |
| Total Demand Alt B | 2.96 | 3.84 | 3.26 |
| Total Demand Alt A | 1.90 | 2.47 | 2.10 |

| Ravenswood | Demand $Mm^3$ | Demand Mt | Demand x 85% Mt |
|---|---|---|---|
| Years 0 - 10 (10%) | 0.19 | 0.25 | 0.21 |
| Years 10 - 20 (20%) | 0.38 | 0.49 | 0.42 |
| Years 20 - 30 (20%) | 0.33 | 0.43 | 0.37 |
| Years 30 - 40 (20%) | 0.25 | 0.33 | 0.28 |
| Years 40 - 50 (20%) | 0.14 | 0.18 | 0.15 |
| Total Demand Alt C | 1.29 | 1.68 | 1.43 |
| Total Demand Alt B | 0.90 | 1.17 | 0.99 |
| Total Demand Alt A | 0.00 | 0.00 | 0.00 |

**Table B-4. Pond demands used in best estimates for Alternatives A, B, and C. Based on averages of demands for 400 ppm and 200 ppm multiplied by 85% for trap efficiency.**

| Alviso | Demand $Mm^3$ | Demand Mt | x 85% Mt |
|---|---:|---:|---:|
| Alternative C | 37.30 | 48.49 | 41.22 |
| Alternative B | 23.20 | 30.16 | 25.64 |
| Alternative A | 14.28 | 18.57 | 15.78 |

| Eden Landing | Demand $Mm^3$ | Demand Mt | x 85% Mt |
|---|---:|---:|---:|
| Alternative C | 5.95 | 7.73 | 6.57 |
| Alternative B | 3.96 | 5.15 | 4.38 |
| Alternative A | 2.51 | 3.26 | 2.77 |

| Ravenswood | Demand $Mm^3$ | Demand Mt | x 85% Mt |
|---|---:|---:|---:|
| Alternative C | 2.13 | 2.76 | 2.35 |
| Alternative B | 1.43 | 1.87 | 1.59 |
| Alternative A | 0.00 | 0.00 | 0.00 |

# Appendix B

### Table B1. Pond sediment accumulation volumes for Alternative C calculated for 200 ppm and 400 ppm using MARSH98.

| Alviso | Alternative C 400 ppm | Alternative C 200 ppm |
|---|---|---|
| *Years 0 - 10* | 39,719,953 | 20,707,220 |
| *Years 10 - 20* | 8,039,574 | 12,087,594 |
| *Years 20 - 30* | 1,752,041 | 6,862,320 |
| *Years 30 - 40* | 801,654 | 4,091,264 |
| *Years 40 - 50* | 788,419 | 2,705,875 |
| Total | 51,101,641 | 46,454,273 |

| Eden Landing | Alternative C 400 ppm | Alternative C 200 ppm |
|---|---|---|
| *Years 0 - 10* | 5,618,145 | 2,307,784 |
| *Years 10 - 20* | 2,289,730 | 1,731,184 |
| *Years 20 - 30* | 1,365,456 | 1,239,006 |
| *Years 30 - 40* | 880,437 | 865,127 |
| *Years 40 - 50* | 664,964 | 573,198 |
| Total | 10,818,732 | 6,716,300 |

| Ravenswood | Alternative C 400 ppm | Alternative C 200 ppm |
|---|---|---|
| *Years 0 - 10* | 1,942,823 | 703,311 |
| *Years 10 - 20* | 1,057,012 | 568,761 |
| *Years 20 - 30* | 613,822 | 379,033 |
| *Years 30 - 40* | 436,329 | 241,804 |
| *Years 40 - 50* | 335,625 | 5,662 |
| Total | 4,385,610 | 1,898,572 |

# Appendix B

**Table B2. Pond sediment demand volumes calculated for 400 ppm using 10% demand in year zero, 30% at year 10, 50% at year 20 (alternative B), 70% at year 30 and 90% at year 40 (alternative C).**

| Alviso | Demand $Mm^3$ | Demand Mt | Demand x 85% Mt |
|---|---:|---:|---:|
| Years 0 - 10 (10%) | 5.11 | 6.64 | 5.64 |
| Years 10 - 20 (20%) | 10.06 | 13.08 | 11.12 |
| Years 20 - 30 (20%) | 9.90 | 12.87 | 10.94 |
| Years 30 - 40 (20%) | 9.55 | 12.42 | 10.56 |
| Years 40 - 50 (20%) | 7.94 | 10.33 | 8.78 |
| Total Demand Alt C | 42.57 | 55.34 | 47.04 |
| Total Demand Alt B | 25.08 | 32.60 | 27.71 |
| Total Demand Alt A | 15.17 | 19.72 | 16.76 |

| Eden Landing | Demand $Mm^3$ | Demand Mt | |
|---|---:|---:|---:|
| Years 0 - 10 (10%) | 1.08 | 1.41 | 1.20 |
| Years 10 - 20 (20%) | 2.03 | 2.64 | 2.24 |
| Years 20 - 30 (20%) | 1.85 | 2.41 | 2.05 |
| Years 30 - 40 (20%) | 1.58 | 2.06 | 1.75 |
| Years 40 - 50 (20%) | 1.12 | 1.46 | 1.24 |
| Total Demand Alt C | 7.67 | 9.97 | 8.48 |
| Total Demand Alt B | 4.97 | 6.46 | 5.49 |
| Total Demand Alt A | 3.11 | 4.05 | 3.44 |

| Ravenswood | Demand $Mm^3$ | Demand Mt | |
|---|---:|---:|---:|
| Years 0 - 10 (10%) | 0.44 | 0.57 | 0.48 |
| Years 10 - 20 (20%) | 0.81 | 1.05 | 0.89 |
| Years 20 - 30 (20%) | 0.72 | 0.94 | 0.80 |
| Years 30 - 40 (20%) | 0.60 | 0.78 | 0.66 |
| Years 40 - 50 (20%) | 0.39 | 0.51 | 0.43 |
| Total Demand Alt C | 2.96 | 3.85 | 3.26 |
| Total Demand Alt B | 1.97 | 2.56 | 2.18 |
| Total Demand Alt A | 0.00 | 0.00 | 0.00 |

**Table B3. Pond sediment demand volumes calculated for 200 ppm using 10% demand in year zero, 30% at year 10, 50% at year 20 (alternative B), 70% at year 30 and 90% at year 40 (alternative C).**

| Alviso | Demand $Mm^3$ | Demand Mt | Demand x 85% Mt |
|---|---|---|---|
| Years 0 - 10 (10%) | 4.65 | 6.04 | 5.13 |
| Years 10 - 20 (20%) | 8.75 | 11.37 | 9.66 |
| Years 20 - 30 (20%) | 7.93 | 10.31 | 8.76 |
| Years 30 - 40 (20%) | 6.56 | 8.53 | 7.25 |
| Years 40 - 50 (20%) | 4.14 | 5.38 | 4.57 |
| Total Demand Alt C | 32.03 | 41.64 | 35.37 |
| Total Demand Alt B | 21.33 | 27.72 | 23.56 |
| Total Demand Alt A | 13.40 | 17.41 | 14.80 |

| Eden Landing | Demand $Mm^3$ | Demand Mt | |
|---|---|---|---|
| Years 0 - 10 (10%) | 0.67 | 0.87 | 0.74 |
| Years 10 - 20 (20%) | 1.23 | 1.60 | 1.36 |
| Years 20 - 30 (20%) | 1.06 | 1.37 | 1.16 |
| Years 30 - 40 (20%) | 0.81 | 1.05 | 0.89 |
| Years 40 - 50 (20%) | 0.46 | 0.60 | 0.51 |
| Total Demand Alt C | 4.23 | 5.49 | 4.66 |
| Total Demand Alt B | 2.96 | 3.84 | 3.26 |
| Total Demand Alt A | 1.90 | 2.47 | 2.10 |

| Ravenswood | Demand $Mm^3$ | Demand Mt | |
|---|---|---|---|
| Years 0 - 10 (10%) | 0.19 | 0.25 | 0.21 |
| Years 10 - 20 (20%) | 0.38 | 0.49 | 0.42 |
| Years 20 - 30 (20%) | 0.33 | 0.43 | 0.37 |
| Years 30 - 40 (20%) | 0.25 | 0.33 | 0.28 |
| Years 40 - 50 (20%) | 0.14 | 0.18 | 0.15 |
| Total Demand Alt C | 1.29 | 1.68 | 1.43 |
| Total Demand Alt B | 0.90 | 1.17 | 0.99 |
| Total Demand Alt A | 0.00 | 0.00 | 0.00 |

**Table B4. Pond demands used in best estimates for Alternatives A, B and C. Based on averages of demands for 200 ppm and 400 ppm multiplied by 85% for trap efficiency.**

| Alviso | Demand $Mm^3$ | Demand Mt | x 85% Mt |
|---|---|---|---|
| Alternative C | 37.30 | 48.49 | 41.22 |
| Alternative B | 23.20 | 30.16 | 25.64 |
| Alternative A | 14.28 | 18.57 | 15.78 |

| Eden Landing | Demand $Mm^3$ | Demand Mt | x 85% Mt |
|---|---|---|---|
| Alternative C | 5.95 | 7.73 | 6.57 |
| Alternative B | 3.96 | 5.15 | 4.38 |
| Alternative A | 2.51 | 3.26 | 2.77 |

| Ravenswood | Demand $Mm^3$ | Demand Mt | x 85% Mt |
|---|---|---|---|
| Alternative C | 2.13 | 2.76 | 2.35 |
| Alternative B | 1.43 | 1.87 | 1.59 |
| Alternative A | 0.00 | 0.00 | 0.00 |

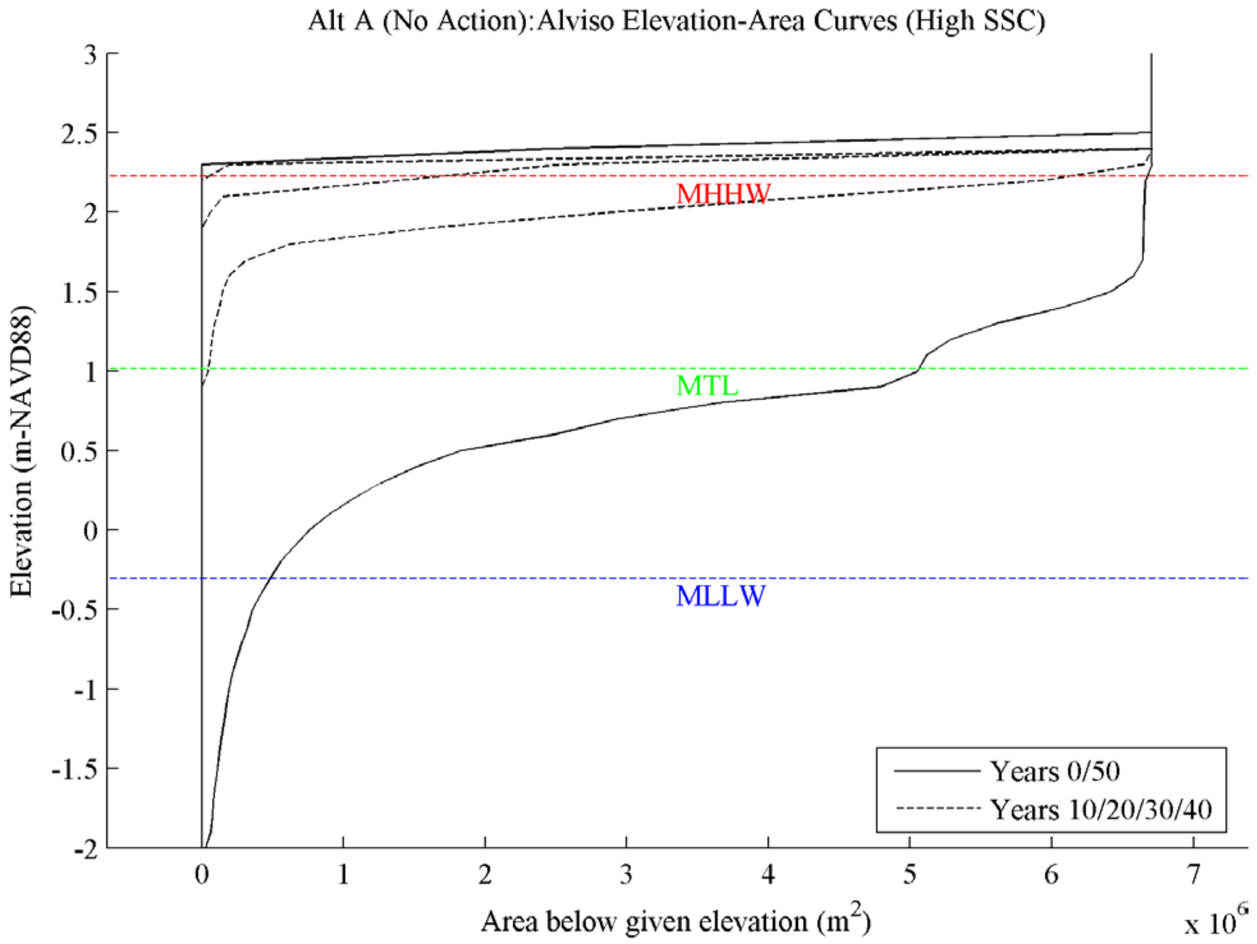


*figure* *B-1*

*South Bay Salt Pond Restoration Project*

## Alt A (No Action): Alviso Elevation-Area Curves (High SSC)

PWA Ref# 1750-03d

PWA

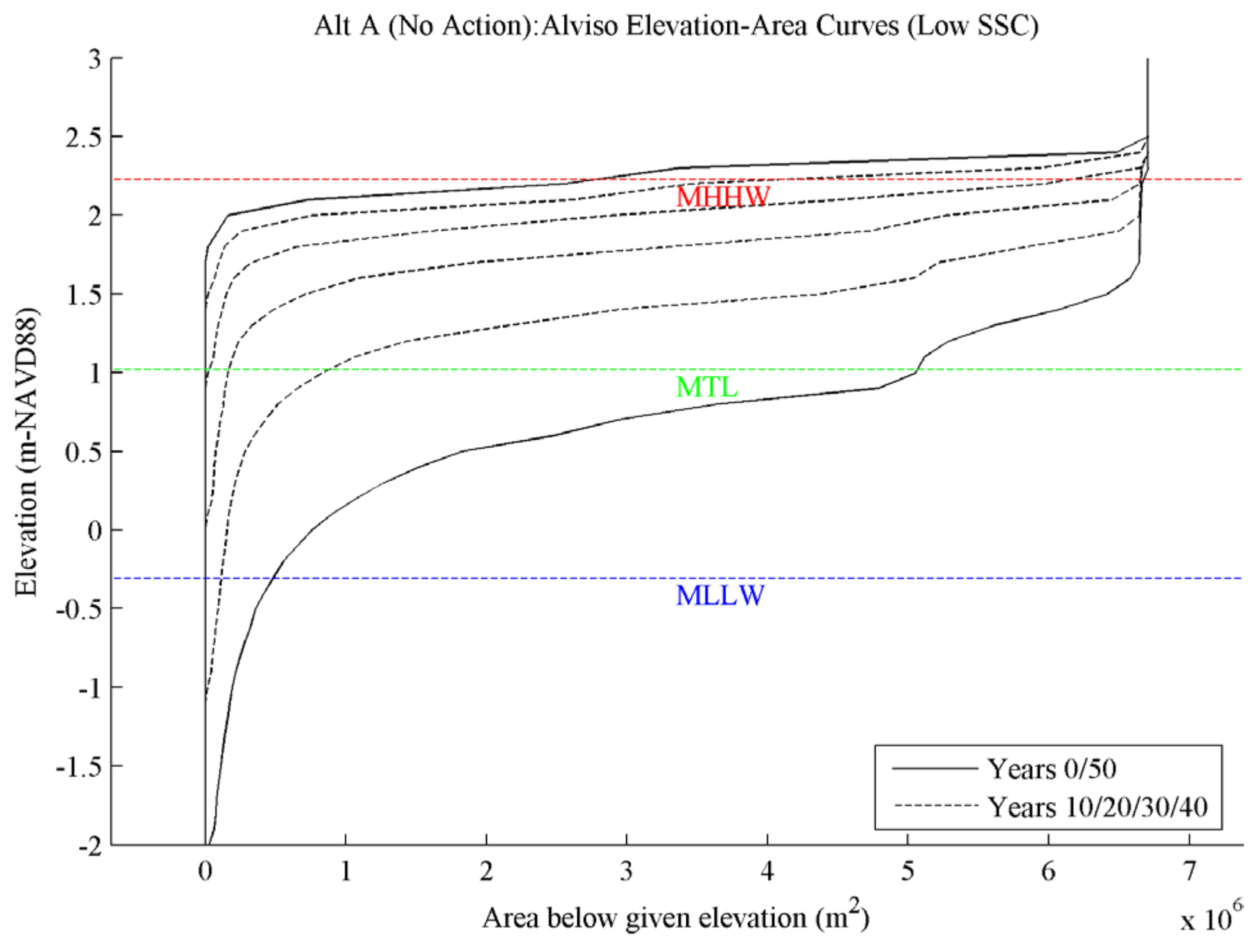


*figure* *B-2*

*South Bay Salt Pond Restoration Project*

Alt A (No Action): Alviso Elevation-Area Curves
(Low SSC)

PWA Ref# 1750-03d

PWA

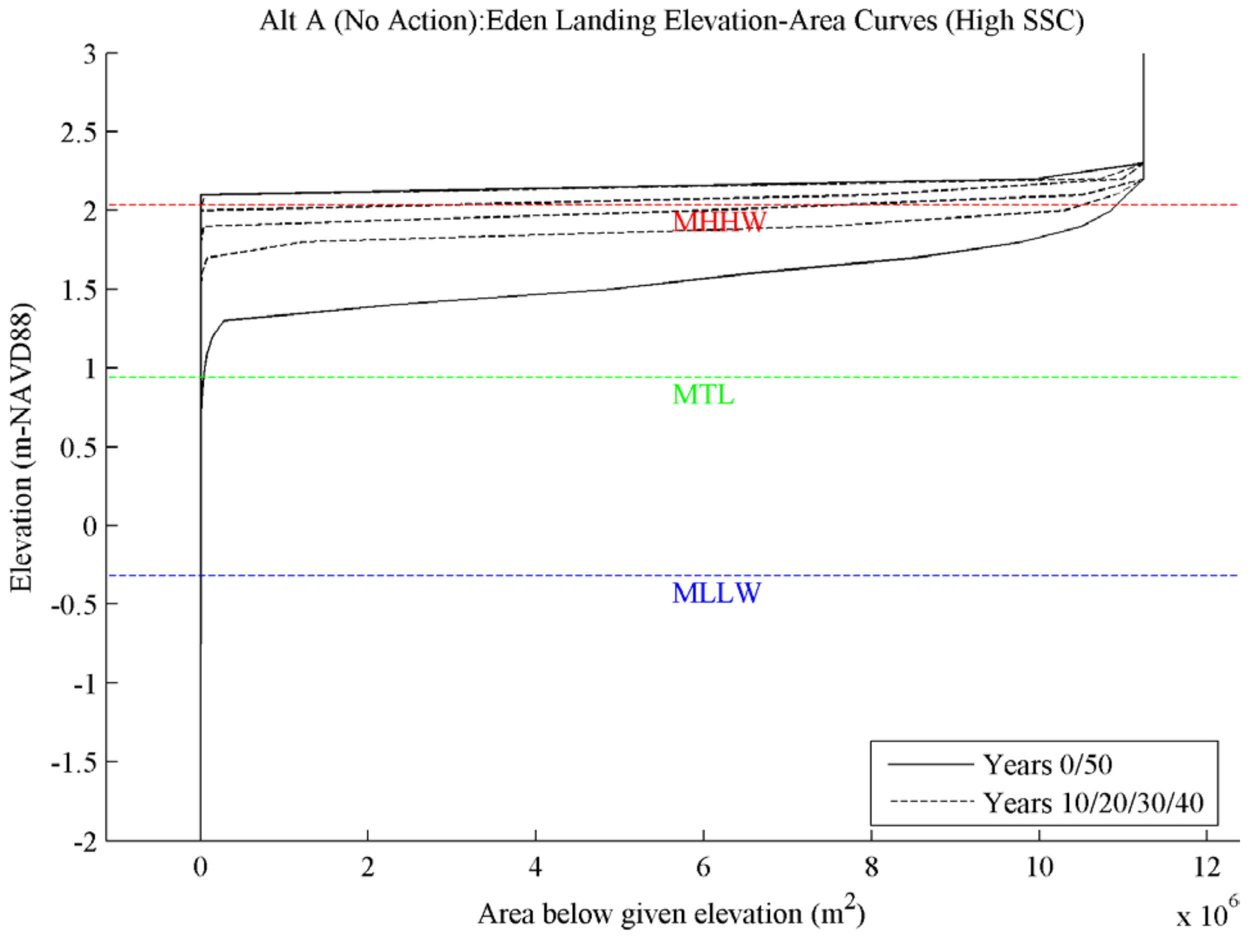


*figure* *B-3*

*South Bay Salt Pond Restoration Project*

Alt A (No Action): Eden Landing Elevation-Area
Curves (High SSC)

PWA Ref# 1750-03d

PWA

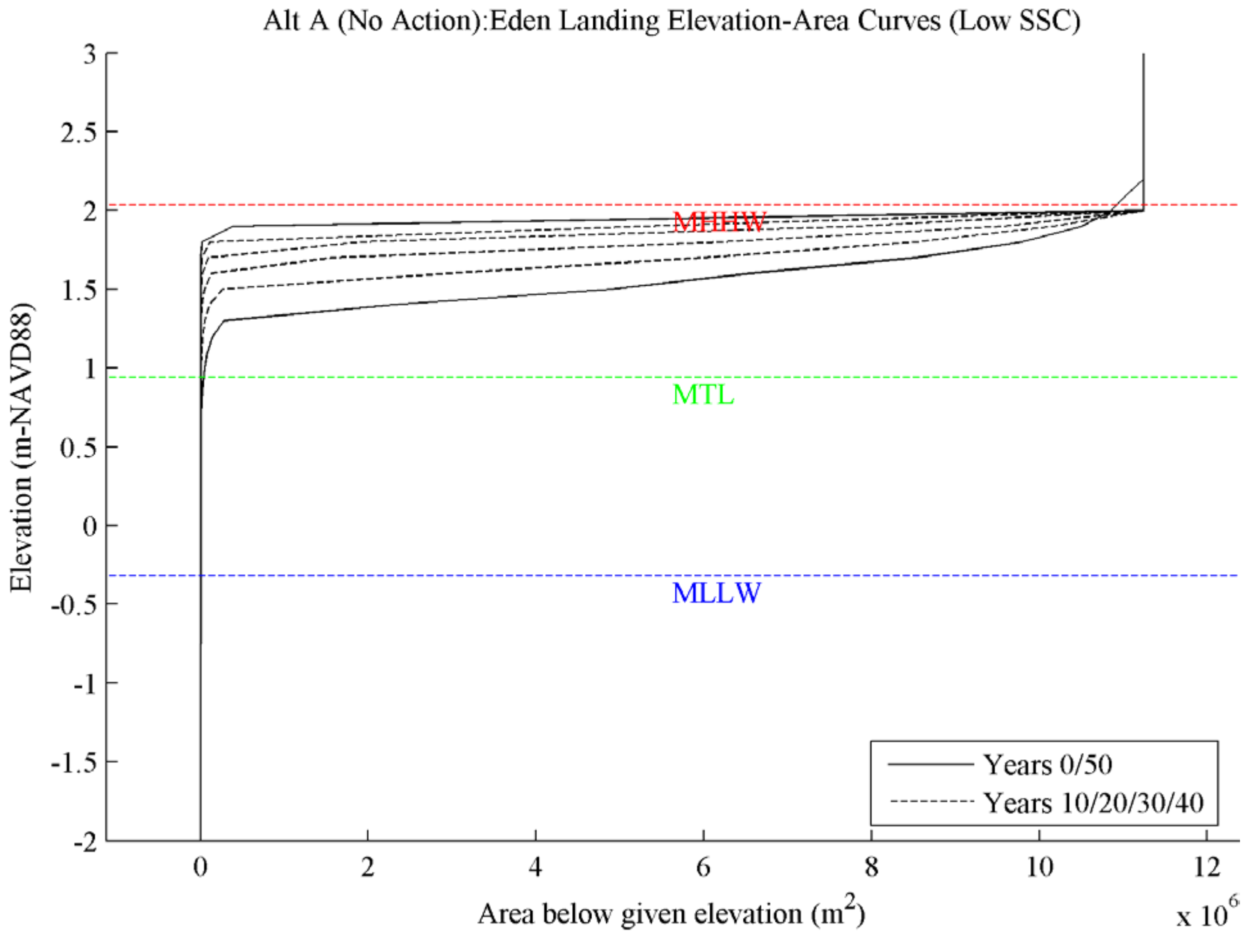


*figure* *B-4*

*South Bay Salt Pond Restoration Project*

Alt A (No Action): Eden Landing Elevation-Area Curves (Low SSC)

PWA Ref# 1750-03d

PWA

\\Orca\pwa\Projects\1750_South_Bay_Salt_Ponds\Task03d_Landscape_Assessment\Geomorphic Assessment Appendix B\Revised\B4_Alt A Eden Landing Low SSC Elevation-Area.doc

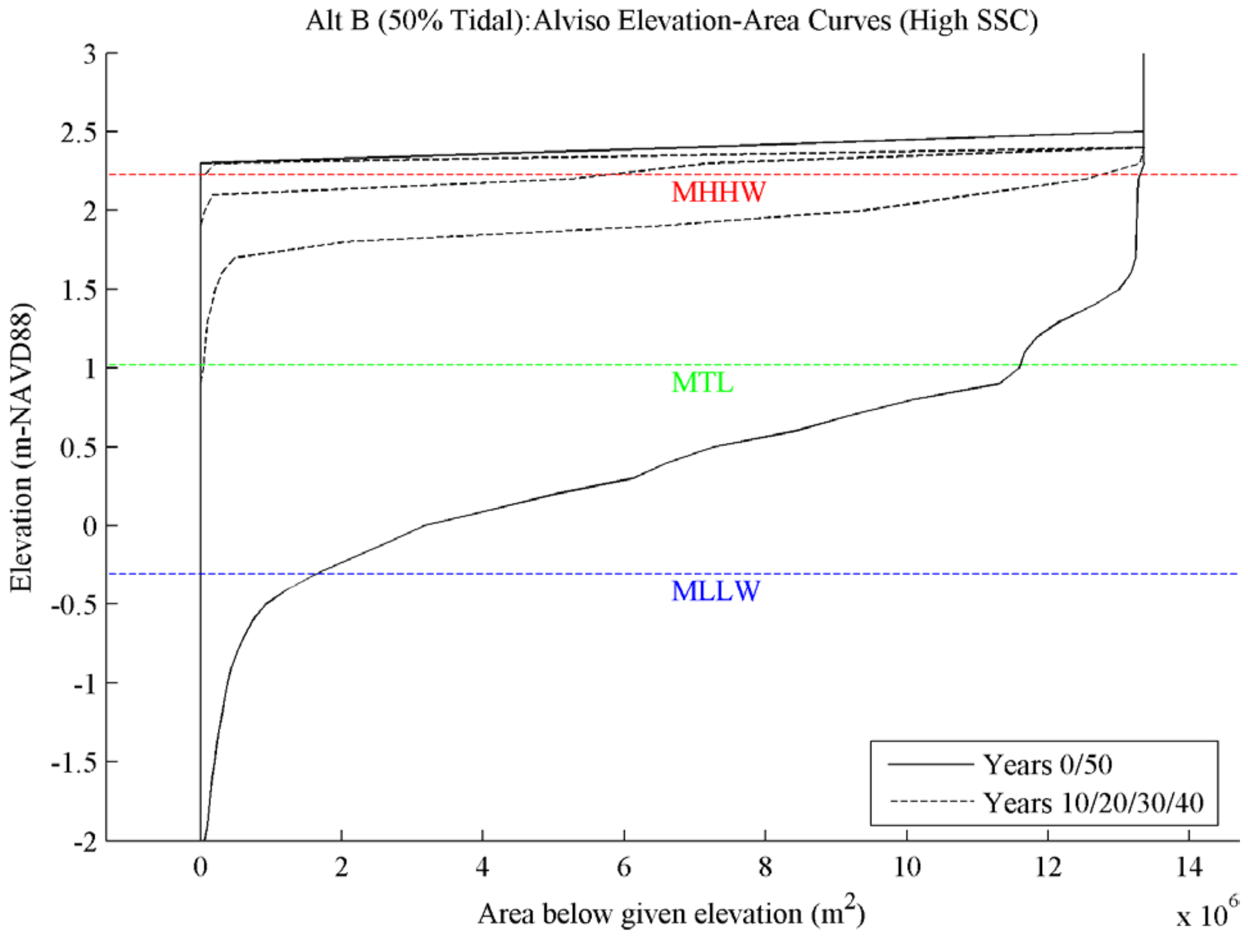


*figure* *B-5*

*South Bay Salt Pond Restoration Project*

Alt B (50% Tidal): Alviso Elevation-Area Curves
(High SSC)

PWA Ref# 1750-03d

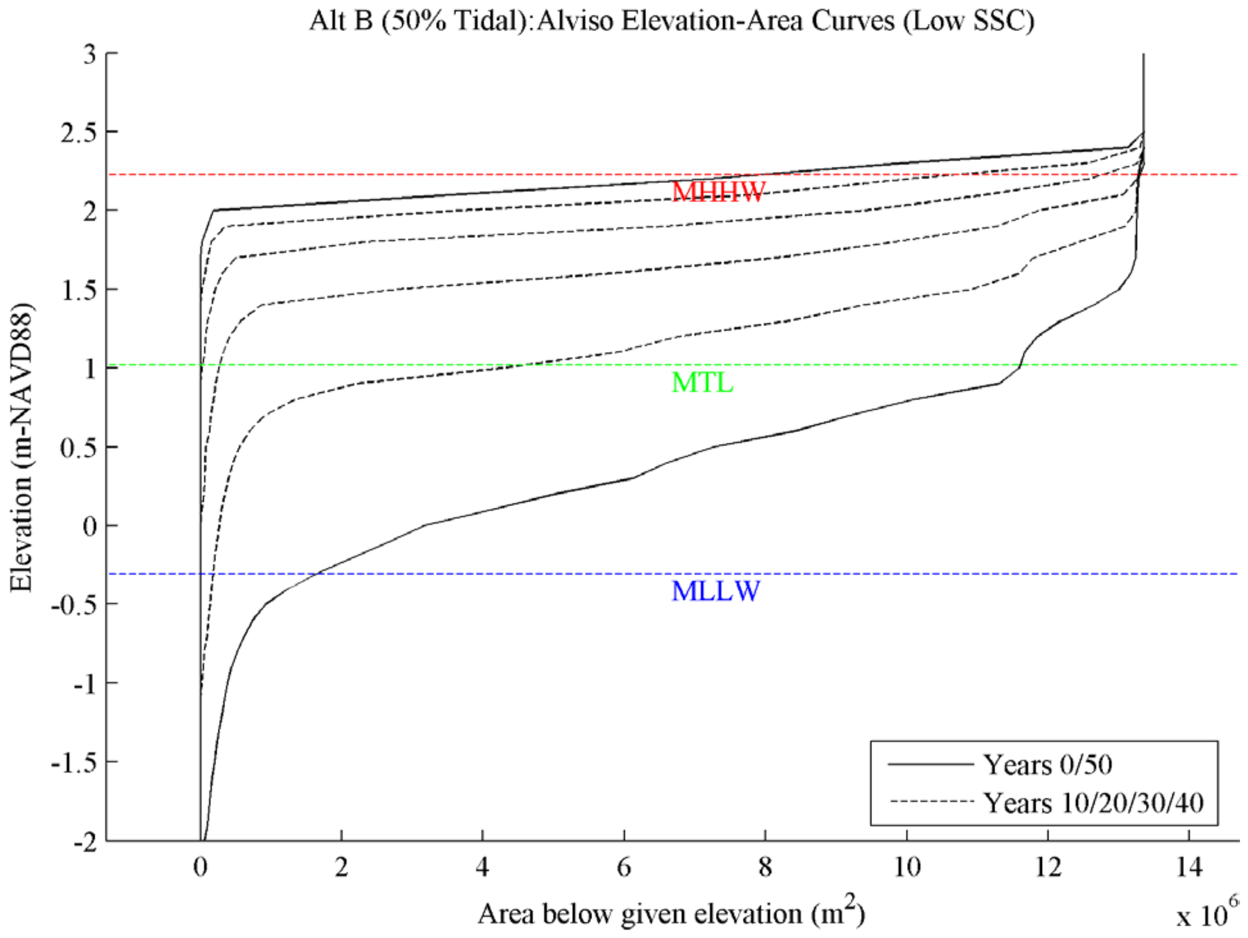


*figure* *B-6*

*South Bay Salt Pond Restoration Project*

Alt B (50% Tidal): Alviso Elevation-Area Curves (Low SSC)

PWA Ref# 1750-03d

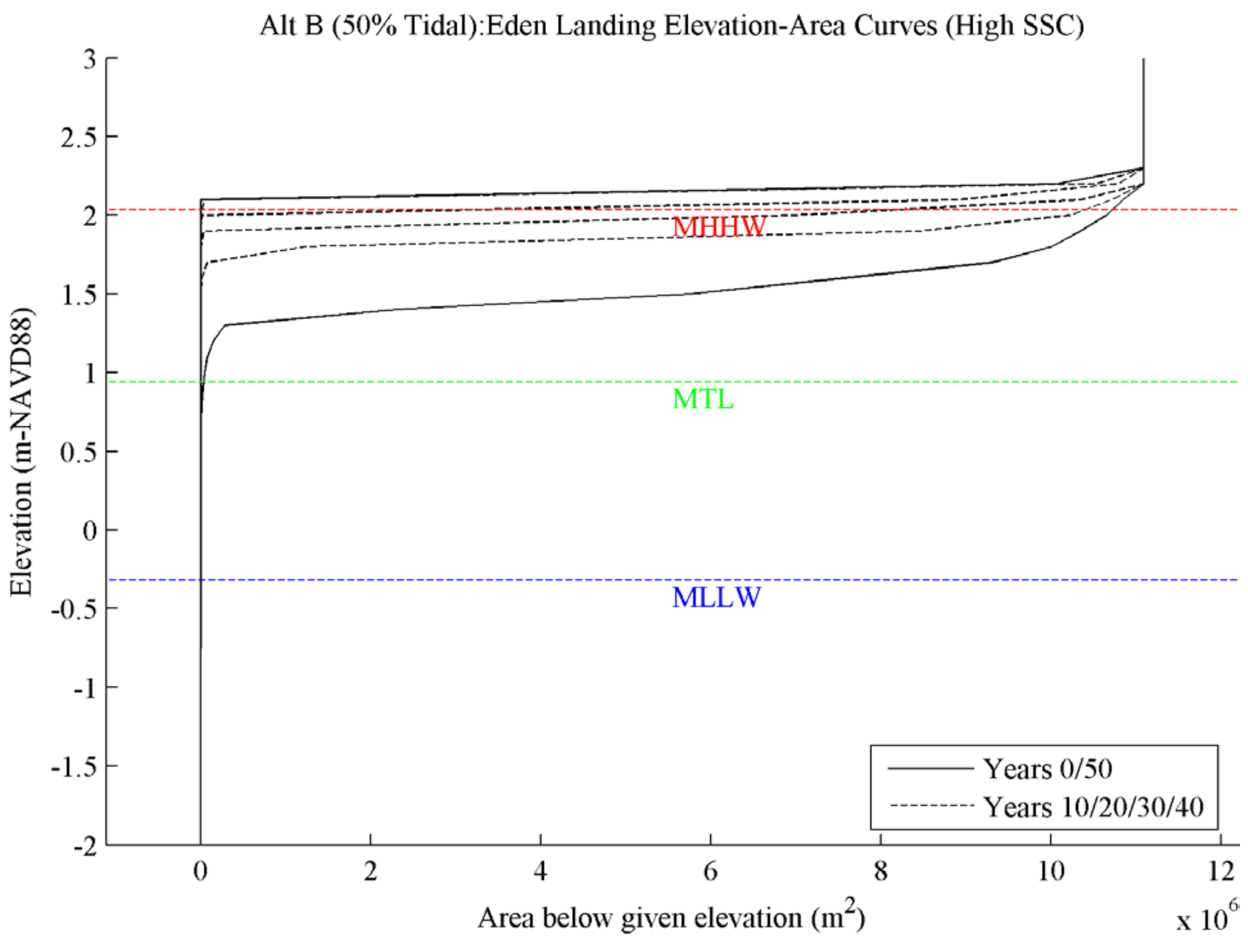


*figure* *B-7*

*South Bay Salt Pond Restoration Project*

Alt B (50% Tidal): Eden Landing Elevation-Area Curves (High SSC)

PWA Ref# 1750-03d

PWA

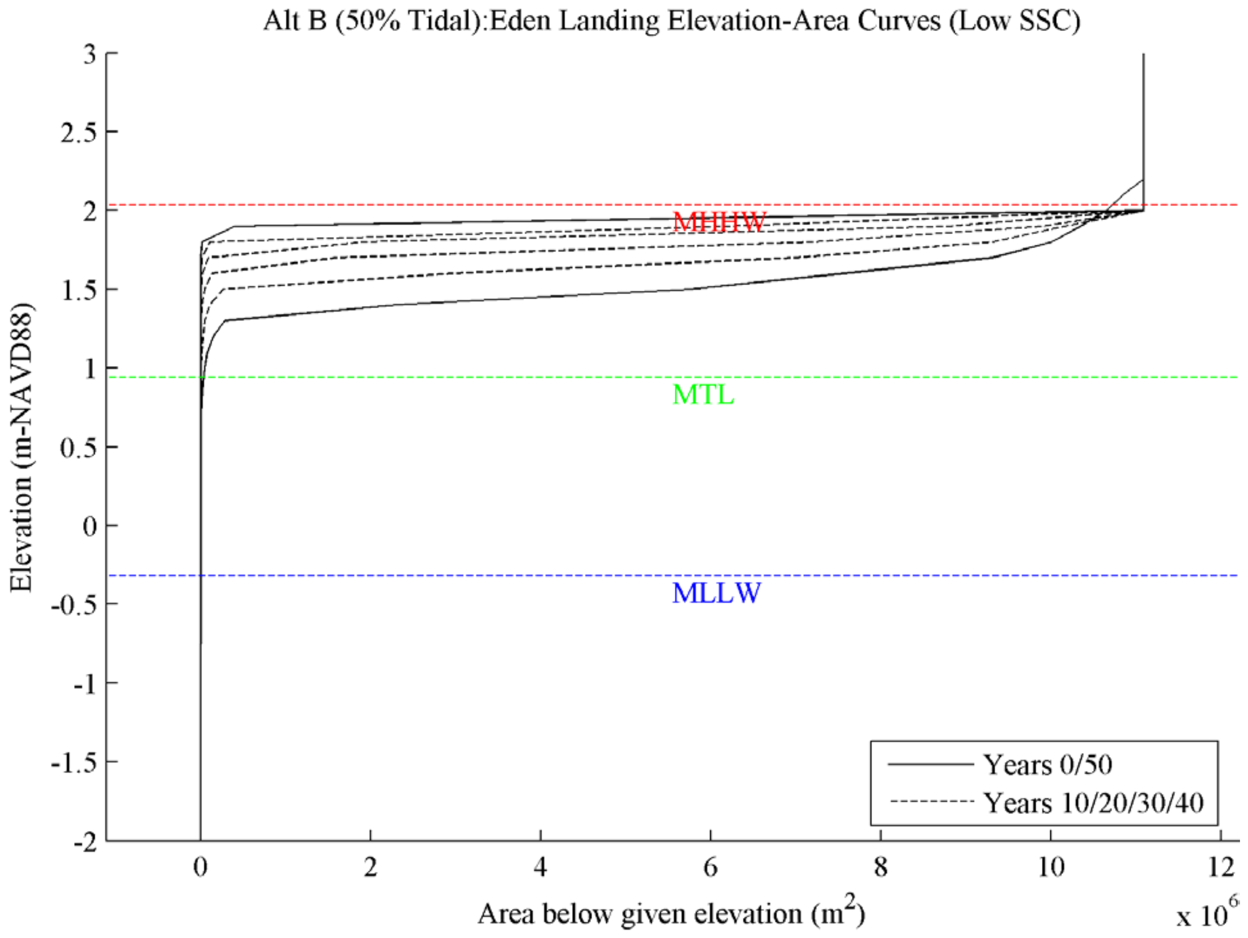


*figure* *B-8*

*South Bay Salt Pond Restoration Project*

Alt B (50% Tidal): Eden Landing Elevation-Area Curves (Low SSC)

PWA Ref# 1750-03d

PWA

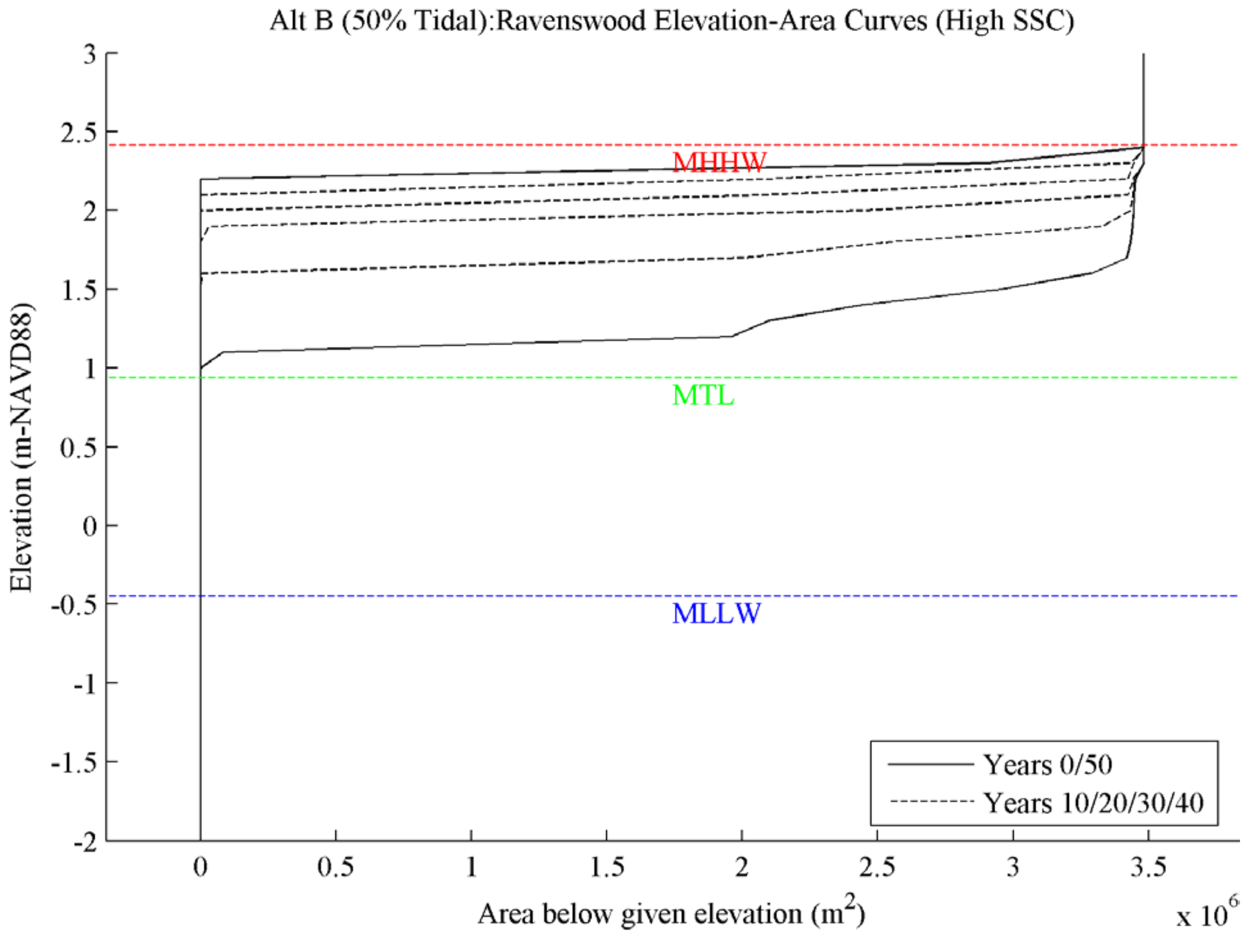


*figure* *B-9*

*South Bay Salt Pond Restoration Project*

Alt B (50% Tidal): Ravenswood Elevation-Area Curves (High SSC)

PWA Ref# 1750-03d

PWA

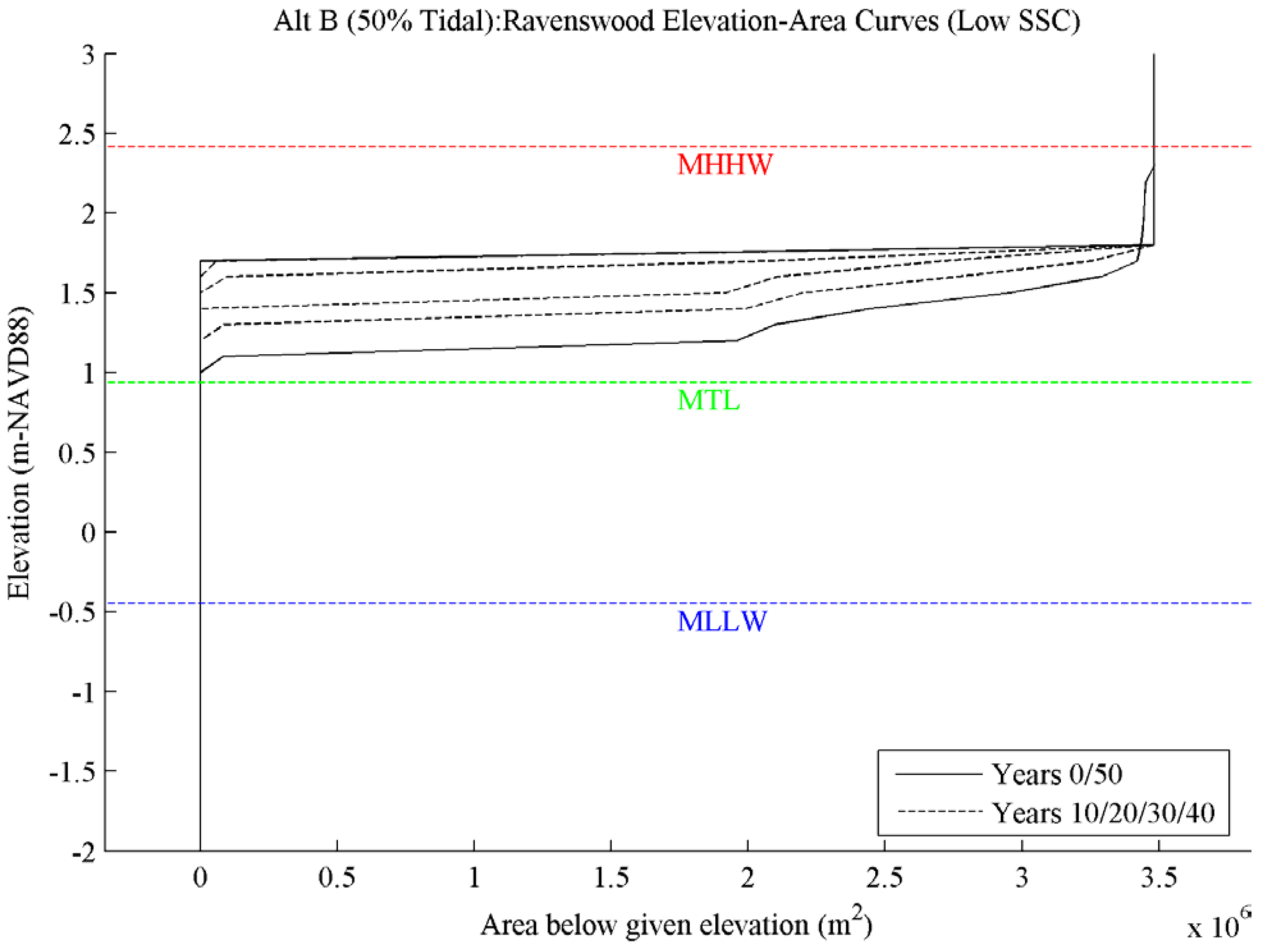


*figure* *B-10*

*South Bay Salt Pond Restoration Project*

Alt B (50% Tidal) Ravenswood Elevation-Area Curves (Low SSC)

PWA Ref# 1750-03d

PWA

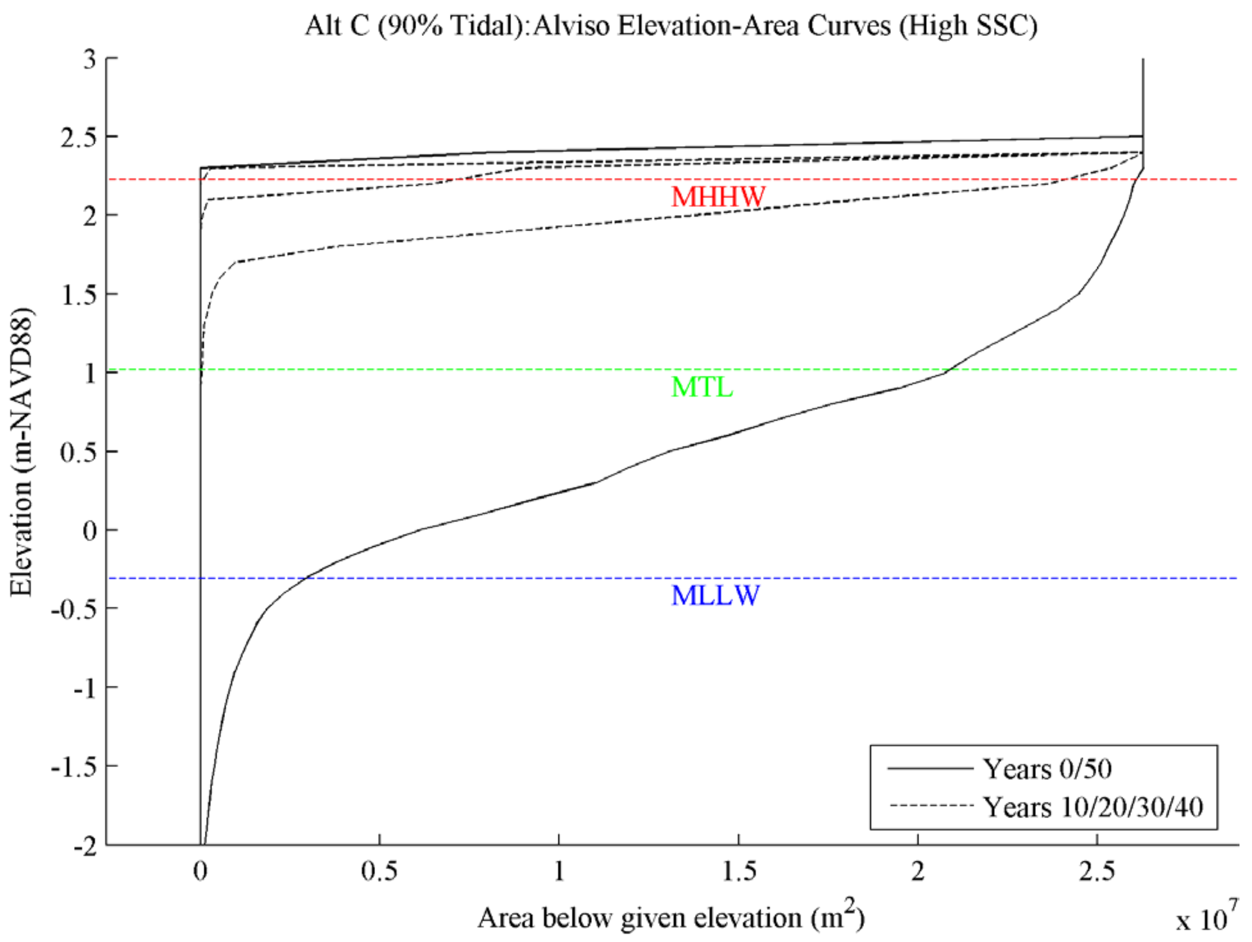


*figure* *B-11*

*South Bay Salt Pond Restoration Project*

Alt C (90% Tidal): Alviso Elevation-Area Curves (High SSC)

PWA Ref# 1750-03d

PWA

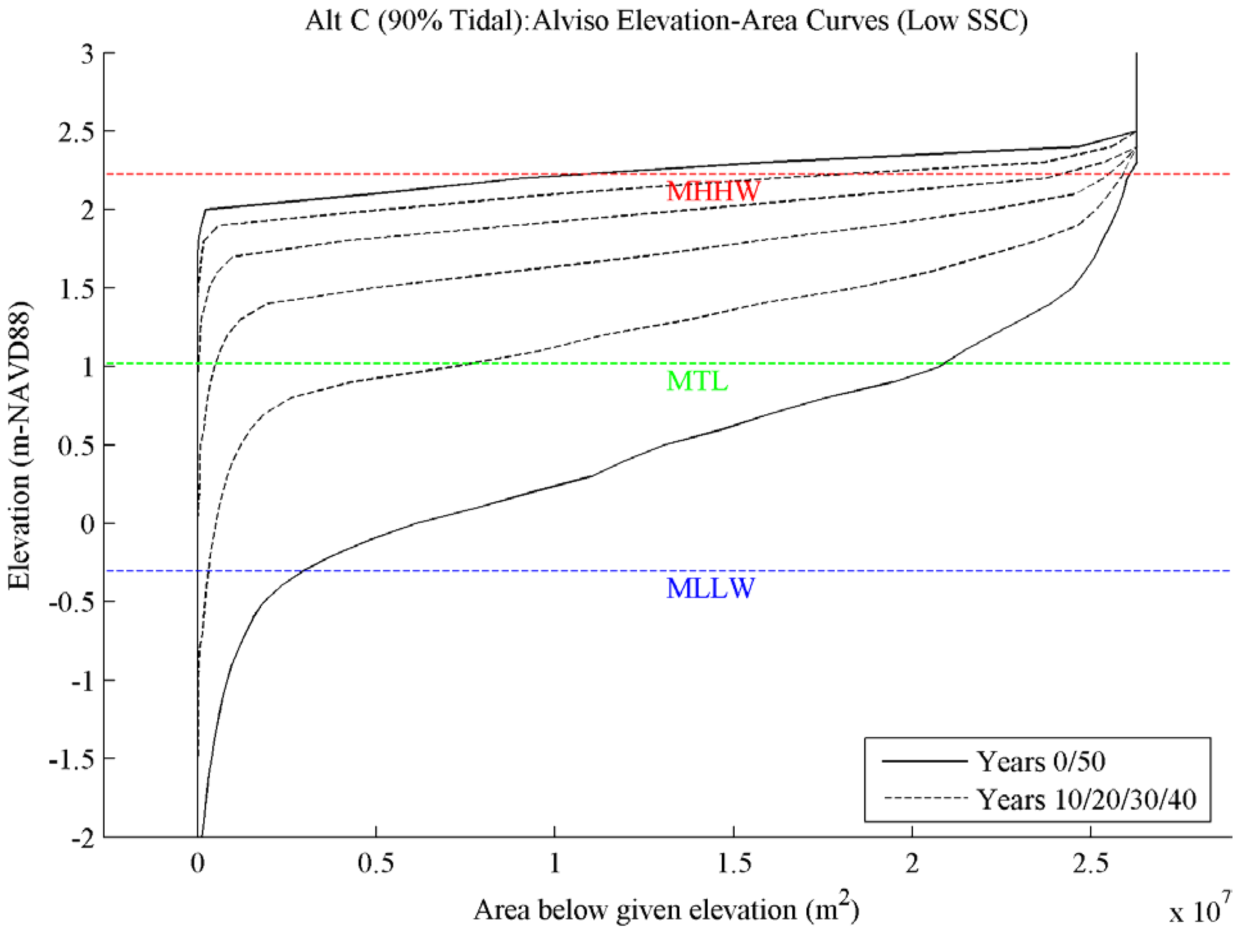


*figure* *B-12*

*South Bay Salt Pond Restoration Project*

Alt C (90% Tidal): Alviso Elevation-Area Curves (Low SSC)

PWA Ref# 1750-03d

PWA

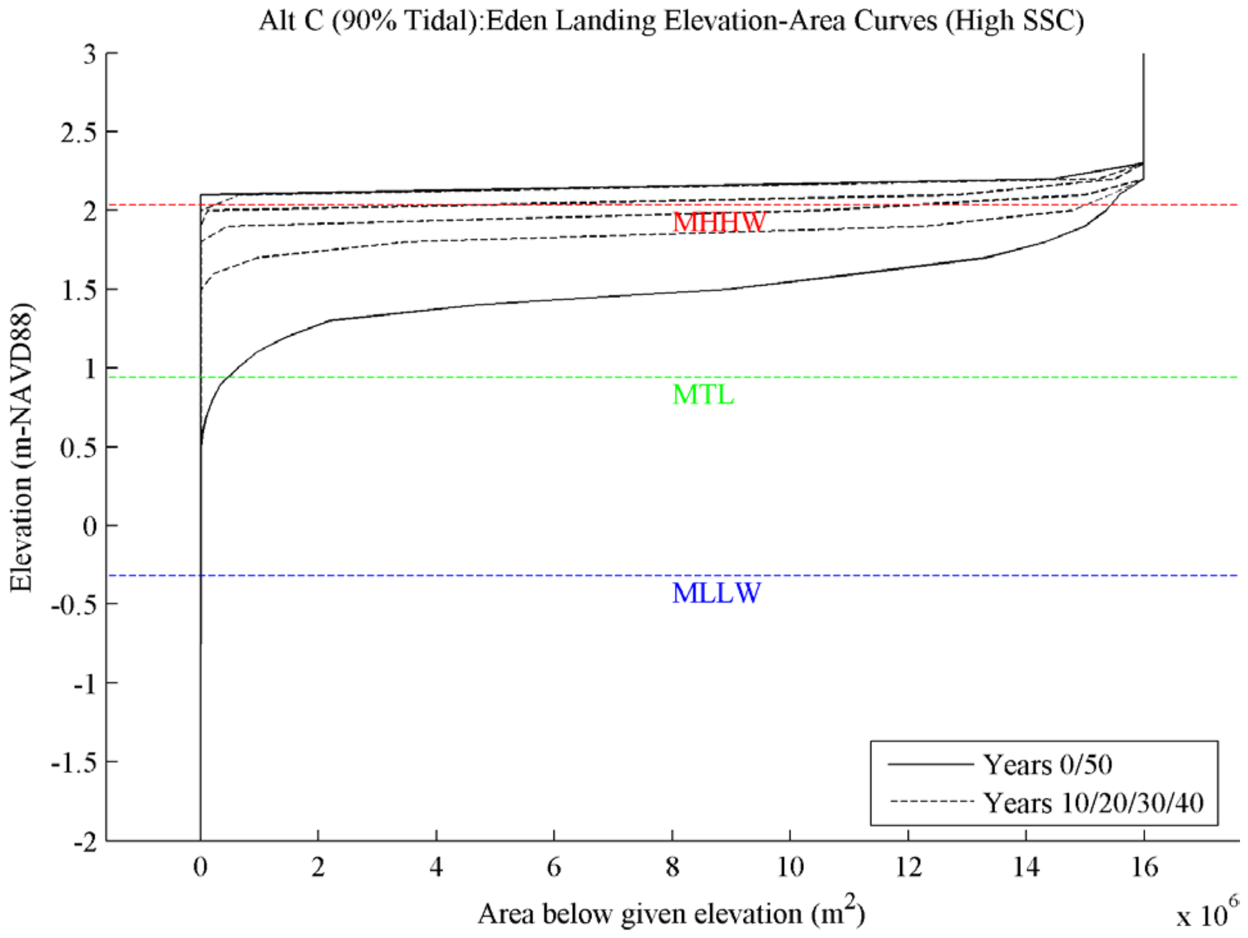


*figure* *B-13*

*South Bay Salt Pond Restoration Project*

Alt C (90% Tidal): Eden Landing Elevation-Area Curves (High SSC)

PWA Ref# 1750-03d

PWA

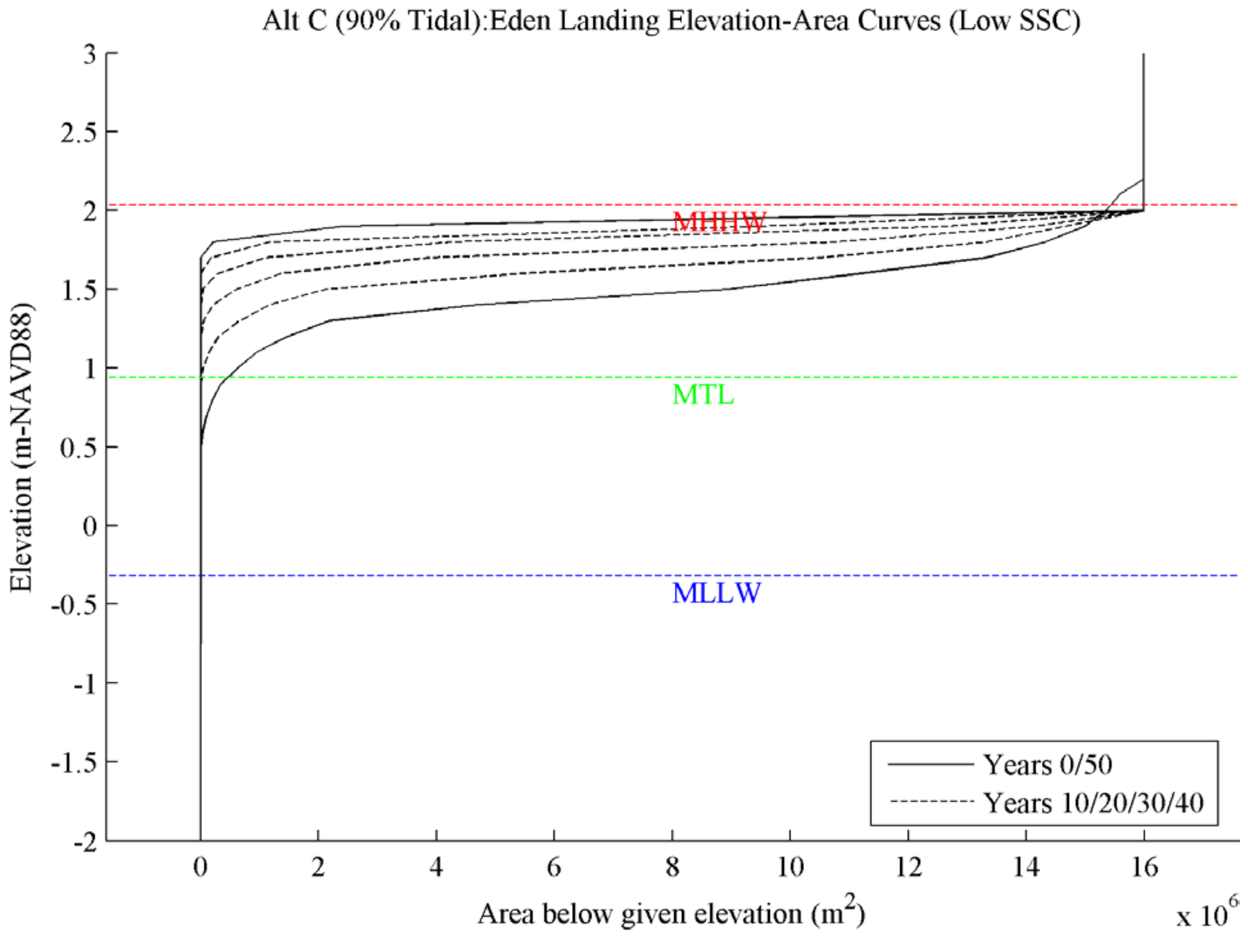


*figure* *B-14*

*South Bay Salt Pond Restoration Project*

Alt C (90% Tidal): Eden Landing Elevation-Area Curves (Low SSC)

PWA Ref# 1750-03d

PWA

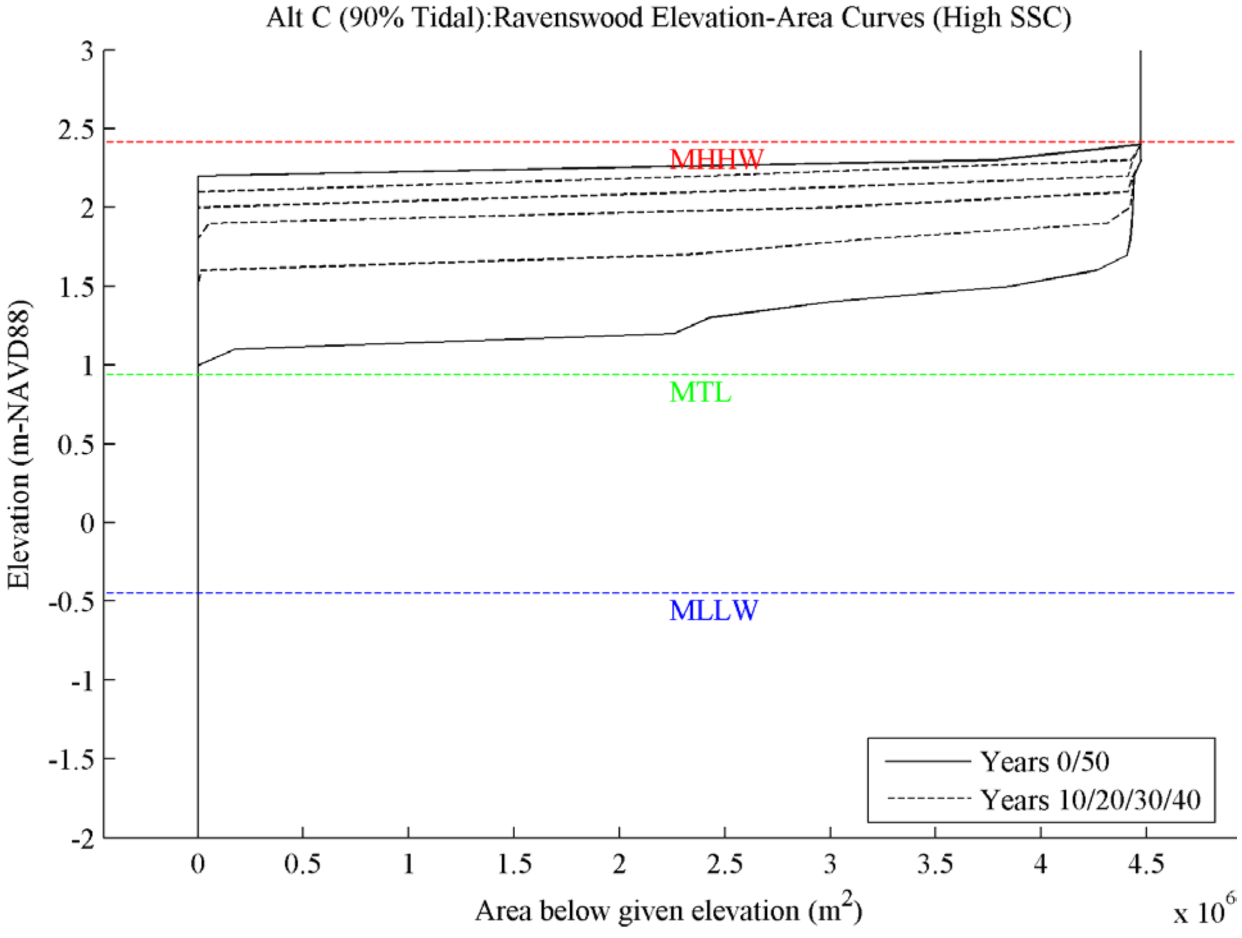


*figure* *B-15*

*South Bay Salt Pond Restoration Project*

Alt C (90% Tidal): Ravenswood Elevation-Area
Curves (High SSC)

PWA Ref# 1750-03d

\\Orca\pwa\Projects\1750_South_Bay_Salt_Ponds\Task03d_Landscape_Assessment\Geomorphic Assessment Appendix B\Revised\B15_Alt C Ravenswood High SSC Elevation-Area.doc

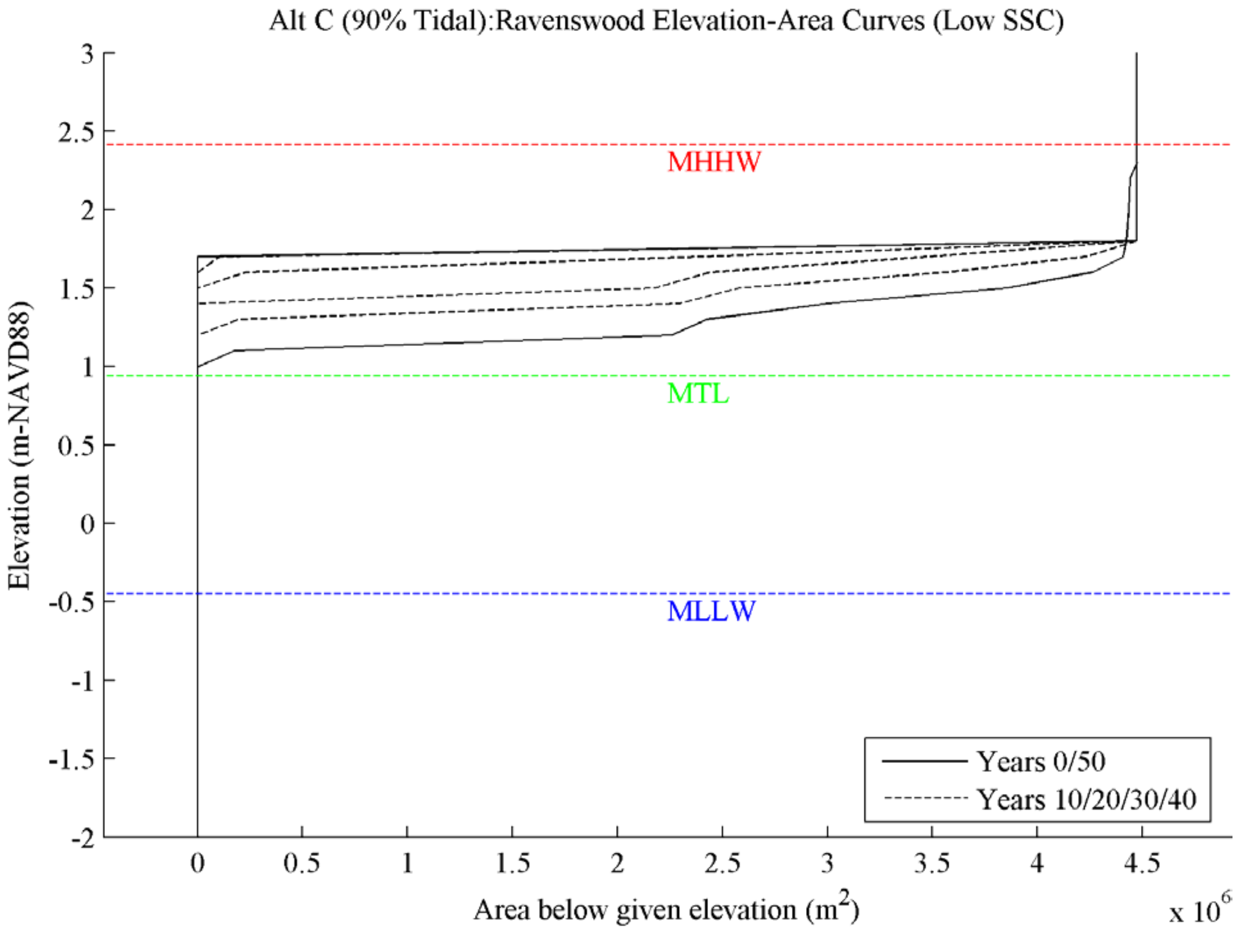


*figure B-16*

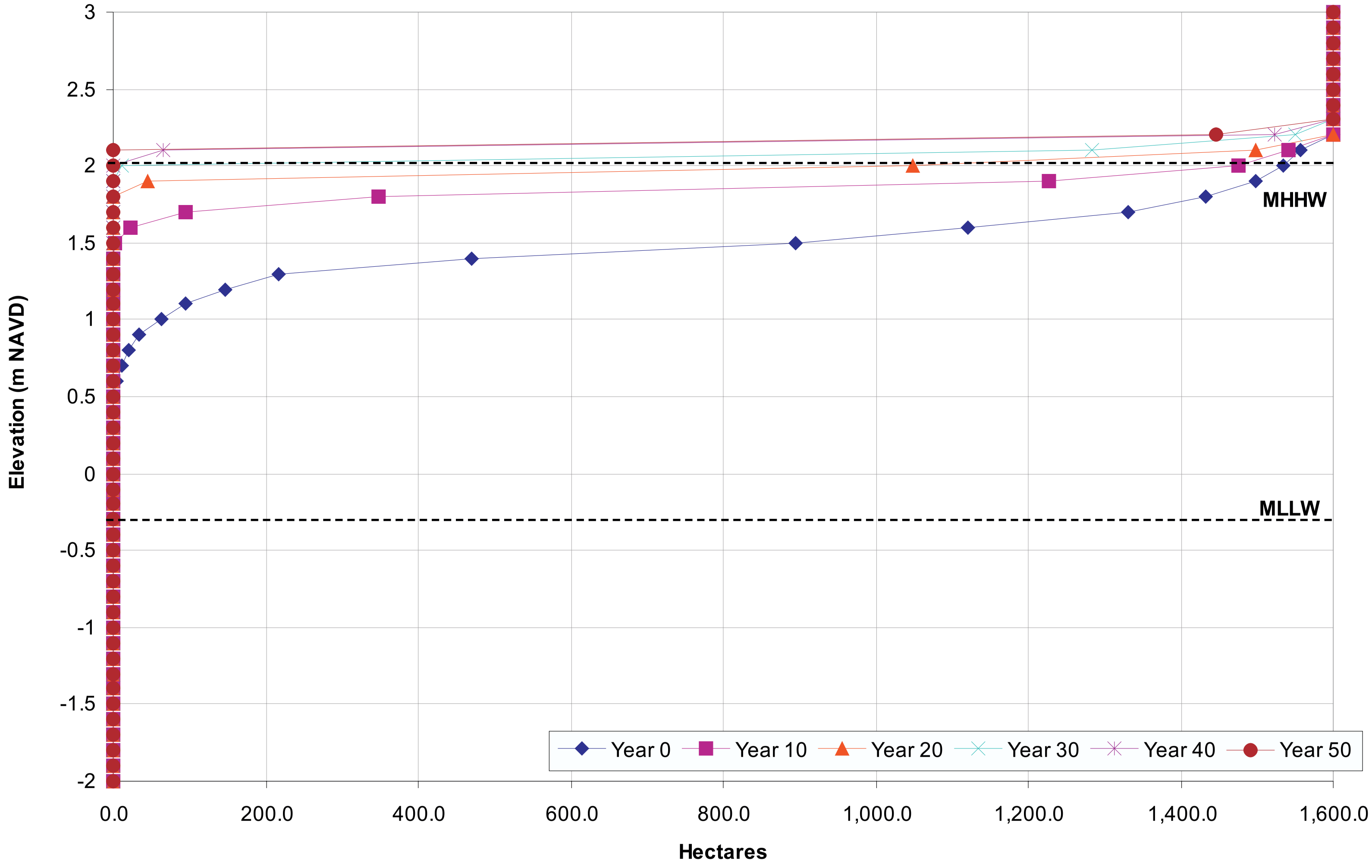
*South Bay Salt Pond Restoration Project*

Alt C (90% Tidal): Ravenswood Elevation-Area Curves (Low SSC)

PWA Ref# 1750-03d

PWA

\\Orca\pwa\Projects\1750_South_Bay_Salt_Ponds\Task03d_Landscape_Assessment\Geomorphic Assessment Appendix B\Revised\B16_Alt C Ravenswood Low SSC Elevation-Area.doc



Notes:
Based on an assumed constant SSC value of 250 mg/L
Based on an assumed constant sea level rise of 3 mm/year

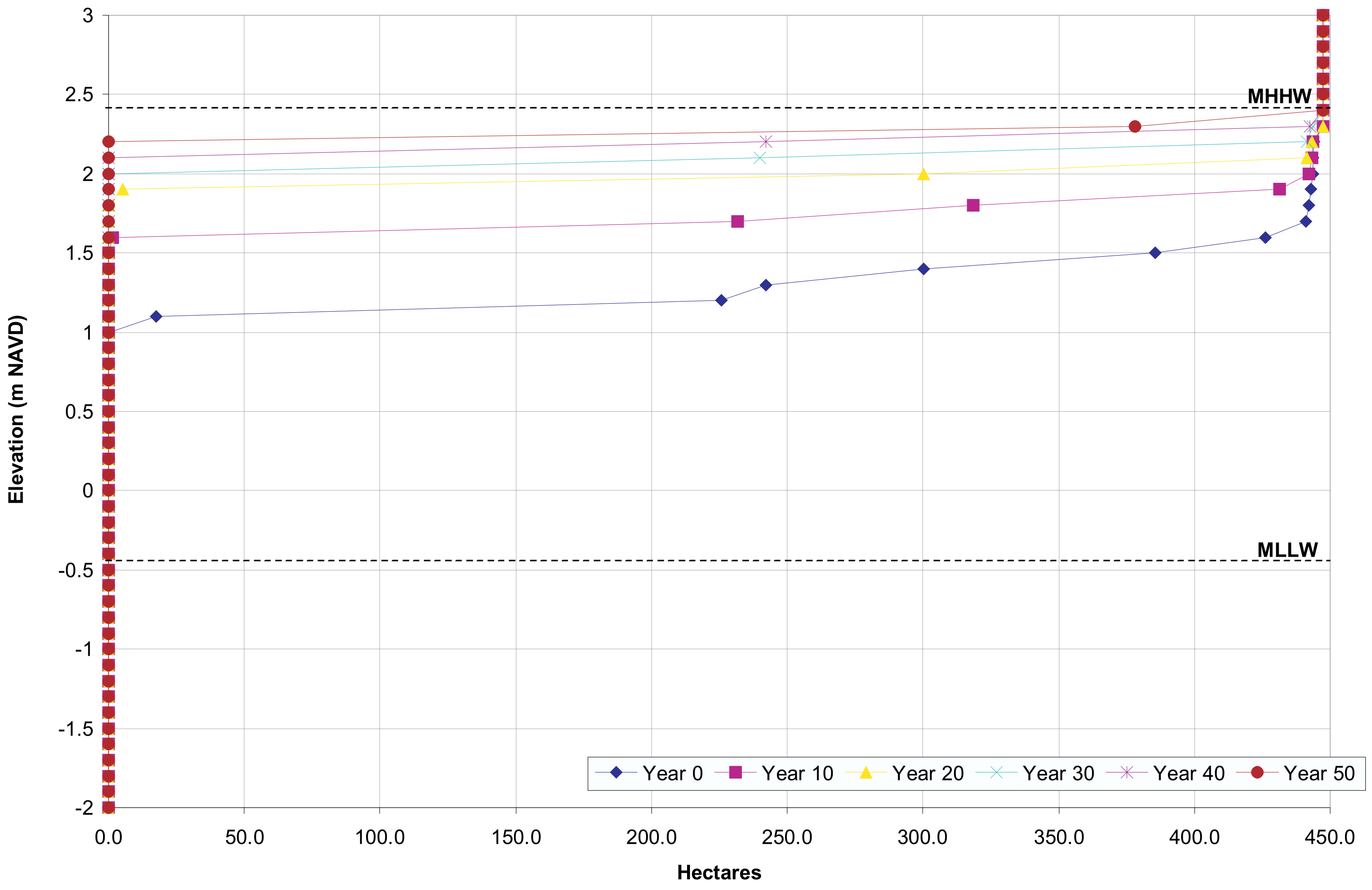
*figure B-17*

*South Bay Salt Pond Restoration Project*

## Eden Landing Complex Hypsometry

Project # 1750.AppB-Figure17hypsmty.cdr

PWA



Notes:
Based on an assumed constant SSC value of 200 mg/L
Based on an assumed constant sea level rise of 3 mm/year

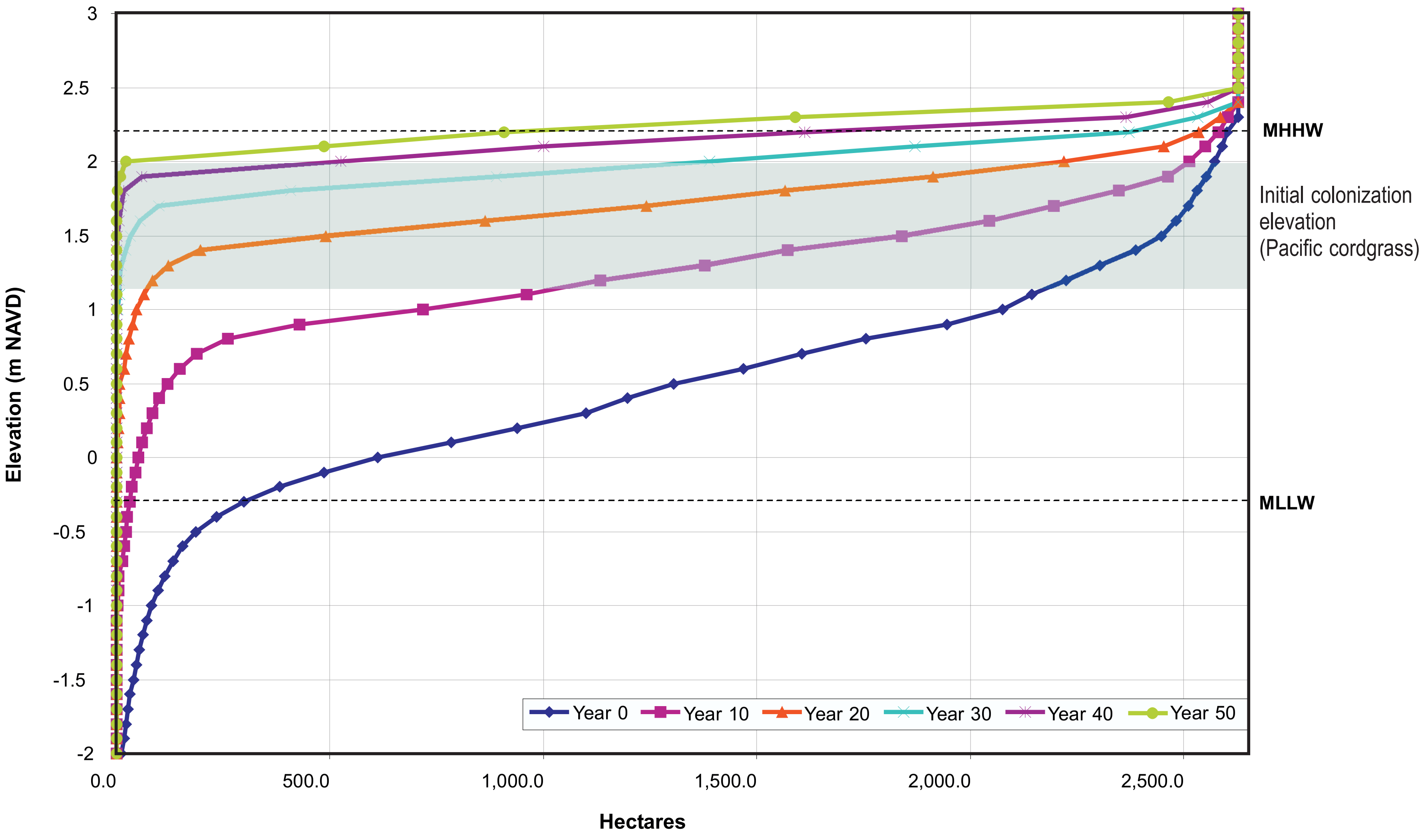
*figure* *B-18*

*South Bay Salt Pond Restoration Project*

**Ravenwood Complex Hypsometry**

Project # 1750.App_2_Raven.cdr

PWA



Notes:
Based on Alternative 3 evolution for the Alviso Complex
Based on an assumed constant SSC value of 200 mg/L
Based on an assumed constant sea level rise of 3 mm/year

*figure B-19*

*South Bay Salt Pond Restoration Project*

## Alviso Complex Hypsometry

Project # 1750.AppBAlvisoHypsomtycdr

PWA

<This page intentionally left blank>

# APPENDIX C.
# ESTIMATES OF TIDAL CHANNEL AND MARSH PAN MORPHOLOGY

<This page intentionally left blank>

# Appendix C. Estimates of Tidal Channel and Marsh Panne Morphology

PWA estimated tidal channel and marsh panne morphology for restored tidal marsh areas in Final Alternatives A, B, and C (Tables 1–3). These estimates were provided to PRBO as input to their bird modeling. Estimates of tidal channel morphology include linear channel length and density, channel lengths by channel order and width class, maximum expected channel widths of the largest channels, total channel areas, and channel areas by channel order and width class. The marsh panne morphology estimates include the average panne size and density and total panne area for different types of marsh pannes.

## Marsh Units and Types

The estimates of tidal channel and marsh morphology are grouped by marsh unit, not by pond. The marsh units correspond to the tidal channel networks and drainage areas shown in the SBSP Final Alternatives Report (PWA and others 2006) graphics. Some marsh units include several ponds and are named by the pond where the mouth of the main tidal channel and levee breach are located. Other ponds are split into more than one marsh unit and are labeled “A” and “B.” The marsh type for each unit is specified as salt marsh or brackish marsh. We do not expect any fresh water marsh. Marsh units A5 and A8N in the Alviso Complex are subdivided into salt marsh and brackish marsh areas. We expect the area of A5 south of the Moffet channel and the southern half of Marsh Unit A8N (including A8S) to be brackish marsh.

## Tidal Channel Estimates

Estimates of tidal channel morphology assume that the restoration design will create large or high order channel systems (i.e. one to three breaches per marsh unit). The estimated channel metrics do not include borrow ditches. Channel metrics are estimated by channel order and classed by channel width (PWA 1995). The width classification assumes an average width for each channel order (San Francisco Estuary Institute 2004), Josh Collins and Robin Grossinger pers. comm., PWA data unpublished). The width of the highest order channels (4th or 5th) are estimated from hydraulic geometry relationships (Williams and others 2002). Channel drainage densities and widths differ for salt marsh and brackish marsh and channel metrics are therefore distinct for each marsh type.

The data used to estimate channel metrics was compared to data collected by PRBO (provided by Diana Stralberg) to assess the consistency of first order channel definitions and drainage densities (linear channel densities). The data sets used for this analysis appear to be consistent with PRBO’s data.

## Marsh Panne Estimates

Our working conceptual model of panne formation is based on input from Josh Collins and distinguishes between the following five types of pannes:

- *Young marsh marshplain pannes:* unvegetated areas of young pickleweed marshes, located away from channels in poorly drained depressions (near channel drainage divides), with bay mud substrate. The pannes at Whale's Tail Marsh are typical of young marsh marshplain pannes. We expect young marsh marshplain pannes to form within the project planning horizon (50 years). Over the long-term, these areas may become vegetated with pickleweed and may not persist.
- *Mature marsh marshplain pannes* (marsh pannes in SFEI's 2004 Science Synthesis): ponded areas on the drainage divides of mature (ancient) marshes that form through biological processes on an organic substrate. The pannes at Petaluma Marsh are typical of mature marsh marshplain pannes. We do not expect mature marsh marshplain pannes to form within the planning horizon, however these pannes may form over the long-term.
- *Foreshore pannes:* Foreshore pannes form in poorly drained areas behind natural berms or wrack at the Bay edge of wind-wave exposed marshes. The pannes in the marsh south of Highway 37 just east of the Napa River are examples of foreshore pannes. We expect only small areas of foreshore pannes to form within the planning horizon. Josh Collins questioned the ecological value of foreshore pannes and said that his understanding was that PRBO did not have bird monitoring data for these features.
- *Backshore pannes:* Backshore pannes form in poorly drained areas at the marsh-upland transition away from the influence of freshwater. Backshore pannes are common at the back edge of young marshes outboard of levees. We expect only small areas of backshore pannes to form within the planning horizon.
- *Salinas* (described in SFEI's 2004 Science Synthesis): Salinas are much larger backshore pannes evident in historic marshes. We do not expect salinas to form naturally in the restored ponds. It may be possible to design backshore pannes somewhat similar to the size of salinas along the upland transition zones away from the influence of freshwater, however we have not evaluated the feasibility or certainty of this design.

Marsh panne estimates are included for three stages of marsh evolution: young marsh, intermediate marsh, and mature marsh. The young marsh and intermediate marsh estimates represent maximum and minimum marsh panne scenarios, respectively.

PRBO's delineation of pannes in young South Bay marshes show a range in panne area of 2% - 10% of marsh area. We have included an estimate for 10% of the marsh area based on data from Whale's Tail Marsh to represent the maximum marsh panne scenario for young marshes. The 10% panne area could also represent a design target for engineering larger pannes by lowering salt pond levees to elevations that would naturally overtop and mimic panne functions. The spatial distribution of these large engineered pannes would be different than the 10% coverage of smaller young marsh marshplain pannes located throughout the marsh.

The intermediate stage of marsh evolution or minimum marsh panne scenario includes only the small area of foreshore and backshore pannes in the model. This scenario gives a lower bracket on the uncertainty in the marsh panne estimates. This scenario could represent an intermediate stage of marsh development when young marsh marshplain pannes have vegetated with pickleweed and mature marsh marshplain pannes have yet to form, leaving only small areas of foreshore and backshore pannes.

We expect long-term conditions to be similar to historic conditions. We have estimated mature marsh marshplain panne areas based on SFEI (2004) data. Based on these estimates, we expect marsh panne areas for long-term conditions to be intermediate to the maximum and minimum marsh panne scenarios.

**Appendix C**

Table 1 Alternative A tidal channel and marsh panne estimates for the SBSP South Bay Geomorphic Assessment

| | | | | | Tidal Channel Estimates | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Channel length (m) by channel order and average width | | | | | Channel length (m) by width class | | | | | | Channel area (ha) by channel order | | | | |
| Pond Complex | GIS Ponds ID | Marsh unit | Marsh type | Marsh unit area | Linear channel density | Length of channel | | 1 | 2 | 3 | 4 | 5* | Small | Medium | Large | Max channel width | Channel area | % marsh area | 1 | 2 | 3 | 4 | 5 |
| | | | | | | | Ave salt marsh channel width (m): | 0 5 | 1 5 | 10 | 20* | | | | | | | | | | | | |
| | | | | (ha) | (km/km2) | (m) | Ave brackish marsh channel width (m): | 0.5 | 1.5 | 10 | 15* | | W < 0.6 m | 0.6 m < W < 4m | W > 4 m | (m) | (ha) | (ha/ha) | | | | | |
| Eden Landing | 95 | E6 | salt | 136 | 20 | 27.200 | | 12,200 | 6.800 | 4,100 | 2,700 | 1.400 | 12,200 | 6.800 | 8.200 | 50 | 18 | 13% | 0 6 | 1 | 4 | 5 | 7 |
| Eden Landing | 95 | E6C | salt | 30 | 20 | 6.100 | | 2.700 | 1.800 | 900 | 600 | | 2.700 | 1.800 | 1.500 | 20 | 3 | 8% | 0 1 | 0 3 | 1 | 1 | |
| Eden Landing | 95 | E12 | salt | 44 | 20 | 8.800 | | 3.900 | 2.600 | 1.300 | 900 | | 3,900 | 2.600 | 2.200 | 30 | 4 | 10% | 0 2 | 0 4 | 1 | 2 | |
| Eden Landing | 95 | E13 | salt | 48 | 20 | 9.600 | | 4,300 | 2.900 | 1.400 | 1.000 | | 4,300 | 2.900 | 2.400 | 30 | 5 | 10% | 0 2 | 0 4 | 1 | 3 | |
| Eden Landing | 105 | E9 | salt | 148 | 20 | 29.600 | | 13,300 | 7.400 | 4.400 | 3.000 | 1,500 | 13,300 | 7.400 | 8.900 | 50 | 20 | 14% | 0 7 | 1.1 | 4 | 6 | 8 |
| Eden Landing | 105 | E14 | salt | 63 | 20 | 12.600 | | 5.700 | 3.100 | 1.900 | 1.300 | 600 | 5,700 | 3.100 | 3.800 | 30 | 7 | 12% | 0 3 | 0.5 | 2 | 3 | 2 |
| Eden Landing | 103 | E8A | salt | 107 | 20 | 21.500 | | 9,700 | 5,400 | 3.200 | 2.100 | 1.100 | 9,700 | 5,400 | 6,400 | 50 | 14 | 13% | 0 5 | 0.8 | 3 | 4 | 5 |
| Eden Landing | 99 | E2 | salt | 272 | 20 | 54.500 | | 24,500 | 13.600 | 8.200 | 5.400 | 2.700 | 24,500 | 13.600 | 16,300 | 80 | 43 | 16% | 1 2 | 2 | 8 | 11 | 21 |
| Eden Landing | 99 | E1 | salt | 108 | 20 | 21.600 | | 9.700 | 5.400 | 3.200 | 2.200 | 1,100 | 9.700 | 5.400 | 6.500 | 50 | 14 | 13% | 0 5 | 0 8 | 3 | 4 | 5 |
| Eden Landing | 99 | E7 | salt | 85 | 20 | 16.900 | | 7.600 | 4.200 | 2.500 | 1.700 | 800 | 7.600 | 4.200 | 5.000 | 40 | 10 | 12% | 0.4 | 0 6 | 3 | 3 | 3 |
| Eden Landing | 96 | E4 | salt | 54 | 20 | 10.700 | | 4.800 | 3.200 | 1.600 | 1,100 | | 4.800 | 3.200 | 2.700 | 30 | 6 | 11% | 0 2 | 0 5 | 1 6 | 3 | |
| Alviso | 134 | A21 | brackish | 59 | 13 | 7.700 | | 3.500 | 2.300 | 1.200 | 800 | | 3.500 | 2.300 | 2.000 | 20 | 3 | 5% | 0 2 | 0 3 | 1 | 1 | |
| Alviso | 138 | A19 | brackish | 107 | 13 | 13.900 | | 6.300 | 4.200 | 2,100 | 1,400 | | 6.300 | 4.200 | 3,500 | 30 | 6 | 6% | 0 3 | 0 6 | 2 | 3 | |
| Alviso | 135 | A20 | brackish | 25 | 13 | 3.300 | | 1.500 | 1.000 | 500 | 300 | | 1.500 | 1.000 | 800 | 20 | 1 | 5% | 0 1 | 0 1 | 1 | 1 | |
| Alviso | 147 | A6-B | salt | 59 | 20 | 11.800 | | 5.300 | 3.500 | 1.800 | 1.200 | | 5.300 | 3.500 | 3.000 | 30 | 6 | 11% | 0 3 | 0 5 | 2 | 4 | |
| Alviso | 147 | A7 | salt | 103 | 20 | 20.700 | | 9,300 | 5.200 | 3.100 | 2.100 | 1.000 | 9,300 | 5.200 | 6,200 | 40 | 13 | 13% | 0 5 | 0 8 | 3 | 4 | 5 |
| Alviso | 146 | A5 | salt | 174 | 20 | 34.800 | | 15.700 | 8.700 | 5.200 | 3.500 | 1,700 | 15.700 | 8.700 | 10,400 | 40 | 21 | 12% | 0 8 | 1 3 | 5 | 7 | 7 |
| Alviso | 146 | A5 | brackish | 75 | 13 | 9.700 | | 4.400 | 2.400 | 1.500 | 1.000 | 500 | 4.400 | 2.400 | 3.000 | 40 | 5 | 7% | 0 2 | 0 4 | 2 | 2 | 2 |
| Alviso | 146 | A6-A | salt | 75 | 20 | 15.000 | | 6.700 | 3.700 | 2.200 | 1.500 | 700 | 6.700 | 3.700 | 4.400 | 40 | 9 | 12% | 0 3 | 0 6 | 2 | 3 | 3 |
| **Subtotals and averages** | | | | | | | | | | | | | | | | | | | | | | | |
| Eden Landing | | | | 1,095 | 20 | 219.100 | | 98.400 | 56.400 | 32.700 | 22.000 | 9.200 | 98.400 | 56.400 | 63.900 | 40 | 140 | 13% | 5 | 8 | 33 | 46 | 51 |
| Alviso | | | | 678 | 17 | 14613 | | 52.700 | 31.000 | 17.600 | 11.800 | 3.900 | 52.700 | 31.000 | 33.300 | 30 | 60 | 9% | 3 | 5 | 18 | 25 | 16 |
| **Totals and averages** | | | | 1,773 | 18 | 233,713 | | 151,100 | 87,400 | 50,300 | 33,800 | 13,100 | 151,100 | 87,400 | 97,200 | 40 | 200 | 11% | 8 | 13 | 50 | 71 | 67 |

* Width of highest order channel is calculated and tabulated under Max channel width

**Appendix C**

Table 1 Alternative A tidal channel and marsh panne estimates for the SBSP South Bay Geomorphic Assessment

| | | | | | Channel area (ha) by width class | | | Marsh Panne Estimates by age of equilibrium (i.e. pickleweed or bulrush marshplain at MHHW) marsh | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Age: Young marsh | | | | | | | | | | | | Intermediate marsh | Mature marsh | | | | |
| | | | | | | | | Panne type: Marshplain | | | | Foreshore | | | | Backshore | | | | | Marshplain | | | | Foreshore and backshore |
| Pond Complex | GIS Ponds ID | Marsh unit | Marsh type | Marsh unit area (ha) | Small W < 0.6 m | Medium 0.6 m < W < 4 m | Large W > 4 m | Ave size (ha) | Density (#/ha) | % marsh area (ha/ha) | Area (ha) | Zone length (m) | Zone width (m) | % zone area (ha/ha) | Area (ha) | Zone length (m) | Zone width (m) | % zone area (ha/ha) | Area (ha) | | Ave size (ha) | Density (#/ha marsh) | % marsh area (ha/ha marsh) | Area (ha) | |
| Eden Landing | 95 | E6 | salt | 136 | 0.6 | 1 | 17 | 0.07 | 1.4 | 10% | 13 | | | | | 1.900 | 30 | 50% | 3 | Areas of foreshore and bachshore pannes are the same as for the Young marsh; no marshplain pannes | 0.04 | 0.5 | 2% | 3 | Areas of foreshore and bachshore pannes are the same as for the Young marsh |
| Eden Landing | 95 | E6C | salt | 30 | 0.1 | 0.3 | 2 | 0.07 | 1.4 | 10% | 3 | | | | | 800 | 30 | 50% | 1 | | 0.04 | 0.5 | 2% | 1 | |
| Eden Landing | 95 | E12 | salt | 44 | 0.2 | 0.4 | 4 | 0.07 | 1.4 | 10% | 4 | | | | | 800 | 30 | 50% | 1 | | 0.04 | 0.5 | 2% | 1 | |
| Eden Landing | 95 | E13 | salt | 48 | 0.2 | 0.4 | 4 | 0.07 | 1.4 | 10% | 5 | | | | | 1.300 | 30 | 50% | 2 | | 0.04 | 0.5 | 2% | 1 | |
| Eden Landing | 105 | E9 | salt | 148 | 0.7 | 1.1 | 18 | 0.07 | 1.4 | 10% | 14 | | | | | | | | | | 0.04 | 0.5 | 2% | 3 | |
| Eden Landing | 105 | E14 | salt | 63 | 0.3 | 0.5 | 7 | 0.07 | 1.4 | 10% | 6 | | | | | | | | | | 0.04 | 0.5 | 2% | 1 | |
| Eden Landing | 103 | E8A | salt | 107 | 0.5 | 0.8 | 12 | 0.07 | 1.4 | 10% | 11 | | | | | | | | | | 0.04 | 0.5 | 2% | 2 | |
| Eden Landing | 99 | E2 | salt | 272 | 1.2 | 2 | 40 | 0.07 | 1.4 | 10% | 27 | | | | | | | | | | 0.04 | 0.5 | 2% | 5 | |
| Eden Landing | 99 | E1 | salt | 108 | 0.5 | 0.8 | 12 | 0.07 | 1.4 | 10% | 11 | | | | | | | | | | 0.04 | 0.5 | 2% | 2 | |
| Eden Landing | 99 | E7 | salt | 85 | 0.4 | 0.6 | 9 | 0.07 | 1.4 | 10% | 8 | | | | | | | | | | 0.04 | 0.5 | 2% | 2 | |
| Eden Landing | 96 | E4 | salt | 54 | 0.2 | 0.5 | 5 | 0.07 | 1.4 | 10% | 5 | | | | | | | | | | 0.04 | 0.5 | 2% | 1 | |
| Alviso | 134 | A21 | brackish | 59 | 0.2 | 0.3 | 3 | 0.07 | 1.4 | 10% | 6 | | | | | | | | | | 0.2 | 0.4 | 8% | 5 | |
| Alviso | 138 | A19 | brackish | 107 | 0.3 | 0.6 | 5 | 0.07 | 1.4 | 10% | 11 | | | | | | | | | | 0.2 | 0.4 | 8% | 9 | |
| Alviso | 135 | A20 | brackish | 25 | 0.1 | 0.1 | 1 | 0.07 | 1.4 | 10% | 2 | | | | | | | | | | 0.2 | 0.4 | 8% | 2 | |
| Alviso | 147 | A6-B | salt | 59 | 0.3 | 0.5 | 6 | 0.07 | 1.4 | 10% | 6 | | | | | | | | | | 0.04 | 0.5 | 2% | 1 | |
| Alviso | 147 | A7 | salt | 103 | 0.5 | 0.8 | 12 | 0.07 | 1.4 | 10% | 10 | | | | | | | | | | 0.04 | 0.5 | 2% | 2 | |
| Alviso | 146 | A5 | salt | 174 | 0.8 | 1.3 | 19 | 0.07 | 1.4 | 10% | 17 | | | | | | | | | | 0.04 | 0.5 | 2% | 3 | |
| Alviso | 146 | A5 | brackish | 75 | 0.2 | 0.4 | 5 | 0.07 | 1.4 | 10% | 7 | | | | | | | | | | 0.2 | 0.4 | 8% | 6 | |
| Alviso | 146 | A6-A | salt | 75 | 0.3 | 0.6 | 8 | 0.07 | 1.4 | 10% | 7 | | | | | | | | | | 0.04 | 0.5 | 2% | 1 | |
| **Subtotals and averages** | | | | | | | | | | | | | | | | | | | | | | | | | |
| Eden Landing | | | | 1,095 | 5 | 8 | 130 | 0.07 | 1.4 | 10% | 110 | | | | | 1.200 | 30 | 50% | 7 | | 0.04 | 0.5 | 2% | 20 | |
| Alviso | | | | 678 | 3 | 5 | 58 | 0.07 | 1.4 | 10% | 70 | | | | | | | | | | 0.12 | 0.5 | 5% | 30 | |
| **Totals and averages** | | | | 1,773 | 8 | 13 | 188 | 0.07 | 1.4 | 10% | 180 | | | | | 1,000 | 30 | 50% | 10 | | 0.08 | 0.5 | 4% | 50 | |

**Appendix C**.

Table 2 Alternative B tidal channel and marsh panne estimates for the SBSP South Bay Geomorphic Assessment

| | | | | | | | | | | | | | | **Tidal Channel Estimates** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Channel length (m) by channel order and average width | | | | | | | | | | | | | | | | | | |
| | | | | | | | | 1 | 2 | 3 | 4 | 5* | Channel length (m) by width class | | | | | | | | | | | Channel area (ha) by width class | | |
| Pond Complex | GIS Ponds ID | Marsh unit | Marsh type | Marsh unit area | Linear channel density | Length of channel | Ave salt marsh channel width (m): | 0 5 | 1 5 | 10 | 20* | | Small | Medium | Large | Max channel width | Channel area | % marsh | Channel area (ha) by channel order | | | | | Small | Medium | Large |
| | | | | (ha) | (km/km2) | (m) | Ave brackish marsh channel width (m): | 0.5 | 1.5 | 10 | 15* | | W < 0.6 m | 0.6 m < W < 4m | W > 4 m | (m) | (ha) | area (ha/ha) | 1 | 2 | 3 | 4 | 5 | W < 0.6 m | 0.6 m < W < 4 m | W > 4 m |
| Eden Landing | 95 | E6 | salt | 207 | 20 | 41.500 | | 18.700 | 10.400 | 6.200 | 4.100 | 2.100 | 18.700 | 10 400 | 12,400 | 70 | 31 | 15% | 0 9 | 1 6 | 6 | 8 | 14 | 0 9 | 1 6 | 28 |
| Eden Landing | 105 | E9 | salt | 148 | 20 | 29.600 | | 13,300 | 7.400 | 4.400 | 3.000 | 1.500 | 13,300 | 7 400 | 8.900 | 50 | 20 | 14% | 0 7 | 1 1 | 4 | 6 | 8 | 0 7 | 1 1 | 18 |
| Eden Landing | 103 | E8A | salt | 107 | 20 | 21.500 | | 9,700 | 5.400 | 3.200 | 2.100 | 1.100 | 9,700 | 5 400 | 6.400 | 50 | 14 | 13% | 0 5 | 0 8 | 3 | 4 | 5 | 0 5 | 0 8 | 12 |
| Eden Landing | 103 | E5C | salt | 142 | 20 | 28.400 | | 12.800 | 7,100 | 4.300 | 2.800 | 1.400 | 12.800 | 7,100 | 8,500 | 50 | 19 | 14% | 0 6 | 1.1 | 4 | 6 | 8 | 0 6 | 1.1 | 18 |
| Eden Landing | 98 | E2 | salt | 272 | 20 | 54.500 | | 24.500 | 13,600 | 8.200 | 5 400 | 2 700 | 24.500 | 13,600 | 16.300 | 80 | 43 | 16% | 1 2 | 2 | 8 | 11 | 21 | 1 2 | 2 | 40 |
| Eden Landing | 99 | E1 | salt | 169 | 20 | 33.900 | | 15,200 | 8.500 | 5.100 | 3.400 | 1.700 | 15,200 | 8.500 | 10,200 | 60 | 24 | 14% | 0 8 | 1 3 | 5 | 7 | 10 | 0 8 | 1 3 | 22 |
| Eden Landing | 96 | E4 | salt | 54 | 20 | 10.700 | | 4.800 | 3.200 | 1 600 | 1,100 | | 4.800 | 3.200 | 2.700 | 30 | 6 | 11% | 0 2 | 0 5 | 1.6 | 3 | | 0 2 | 0 5 | 5 |
| Alviso | 134 | A21 | brackish | 59 | 13 | 7.700 | | 3.500 | 2.300 | 1 200 | 800 | | 3.500 | 2.300 | 2.000 | 20 | 3 | 5% | 0 2 | 0 3 | 1 | 1 | | 0 2 | 0 3 | 3 |
| Alviso | 138 | A19 | brackish | 107 | 13 | 13.900 | | 6.300 | 4 200 | 2,100 | 1,400 | | 6.300 | 4.200 | 3,500 | 30 | 6 | 6% | 0 3 | 0 6 | 2 | 3 | | 0 3 | 0 6 | 5 |
| Alviso | 135 | A20 | brackish | 25 | 13 | 3.300 | | 1,500 | 1.000 | 500 | 300 | | 1,500 | 1.000 | 800 | 20 | 1 | 5% | 0 1 | 0 1 | 1 | 1 | | 0 1 | 0 1 | 1 |
| Alviso | 139 | A8 | salt | 111 | 20 | 22.200 | | 10,000 | 5.600 | 3.300 | 2.200 | 1,100 | 10,000 | 5.600 | 6.600 | 50 | 14 | 13% | 0 5 | 0 8 | 3 | 4 | 5 | 0 5 | 0 8 | 13 |
| Alviso | 139 | A8 | brackish | 111 | 13 | 14 400 | | 6.500 | 3.600 | 2.200 | 1.400 | 700 | 6.500 | 3.600 | 4.300 | 50 | 8 | 7% | 0 3 | 0 5 | 2 | 2 | 3 | 0 3 | 0 5 | 8 |
| Alviso | 140 | A6-B | salt | 59 | 20 | 11.800 | | 5.300 | 3.500 | 1.800 | 1.200 | | 5.300 | 3.500 | 3.000 | 30 | 6 | 11% | 0 3 | 0 5 | 2 | 4 | | 0 3 | 0 5 | 6 |
| Alviso | 147 | A7 | salt | 103 | 20 | 20 700 | | 9,300 | 5.200 | 3.100 | 2.100 | 1.000 | 9,300 | 5.200 | 6,200 | 40 | 13 | 13% | 0 5 | 0.8 | 3 | 4 | 5 | 0 5 | 0 8 | 12 |
| Alviso | 146 | A5 | salt | 174 | 20 | 34.800 | | 15.700 | 8.700 | 5.200 | 3.500 | 1,700 | 15.700 | 8.700 | 10,400 | 40 | 21 | 12% | 0 8 | 1 3 | 5 | 7 | 7 | 0 8 | 1 3 | 19 |
| Alviso | 146 | A5 | brackish | 75 | 13 | 9.700 | | 4.400 | 2.400 | 1.500 | 1,000 | 500 | 4.400 | 2.400 | 3.000 | 40 | 5 | 7% | 0 2 | 0 4 | 2 | 2 | 2 | 0 2 | 0 4 | 5 |
| Alviso | 161 | A3N | salt | 37 | 20 | 7.400 | | 3.300 | 2.200 | 1.100 | 700 | | 3.300 | 2.200 | 1.800 | 30 | 3 | 9% | 0 2 | 0 3 | 1 | 2 | | 0 2 | 0 3 | 3 |
| Alviso | 142 | A6-A | salt | 75 | 20 | 15.000 | | 6.700 | 3.700 | 2.200 | 1.500 | 700 | 6.700 | 3.700 | 4 400 | 40 | 9 | 12% | 0 3 | 0 6 | 2 | 3 | 3 | 0 3 | 0 6 | 8 |
| Alviso | 166 | A1-B | salt | 85 | 20 | 16.900 | | 7.600 | 4.200 | 2,500 | 1,700 | 800 | 7.600 | 4.200 | 5 000 | 40 | 10 | 12% | 0 4 | 0 6 | 3 | 3 | 3 | 0 4 | 0 6 | 9 |
| Alviso | 166 | A1-A | salt | 27 | 20 | 5.500 | | 2.500 | 1.600 | 800 | 500 | | 2.500 | 1.600 | 1.300 | 20 | 2 | 9% | 0 1 | 0 2 | 1 | 1 | | 0 1 | 0 2 | 2 |
| Alviso | 165 | A2W-B | salt | 84 | 20 | 16.800 | | 7.600 | 4.200 | 2.500 | 1.700 | 800 | 7 600 | 4.200 | 5.000 | 40 | 10 | 12% | 0 4 | 0 6 | 3 | 3 | 3 | 0 4 | 0.6 | 9 |
| Alviso | 165 | A2W-A | salt | 90 | 20 | 17.900 | | 8.100 | 4.500 | 2.700 | 1.800 | 900 | 8 100 | 4.500 | 5.400 | 40 | 11 | 12% | 0 4 | 0 7 | 3 | 4 | 4 | 0 4 | 0 7 | 10 |
| Alviso | 164 | AB1 | salt | 56 | 20 | 11.200 | | 5.100 | 3.400 | 1.700 | 1,100 | | 5.100 | 3.400 | 2.800 | 30 | 5 | 8% | 0 3 | 0 5 | 2 | 2 | | 0 3 | 0 5 | 4 |
| Alviso | 164 | AB2 | salt | 43 | 20 | 8.600 | | 3,900 | 2.600 | 1.300 | 900 | | 3,900 | 2.600 | 2.200 | 30 | 4 | 8% | 0 2 | 0.4 | 1 | 2 | | 0 2 | 0 4 | 3 |
| Ravenswood | 8 | R4 | salt | 120 | 20 | 24.100 | | 10.800 | 6,000 | 3.600 | 2.400 | 1.200 | 10.800 | 6,000 | 7,200 | 50 | 16 | 13% | 0 5 | 0.9 | 4 | 5 | 6 | 0 5 | 0.9 | 14 |
| Ravenswood | 10 | R1 | salt | 265 | 20 | 53.000 | | 23,800 | 13,200 | 7,900 | 5,300 | 2.600 | 23,800 | 13,200 | 15,800 | 70 | 42 | 16% | 1 2 | 2 | 8 | 11 | 20 | 1 2 | 2 | 38 |
| Ravenswood | 227 | SF2 | salt | 30 | 20 | 6.000 | | 2.700 | 1 800 | 900 | 600 | | 2.700 | 1.800 | 1.500 | 20 | 3 | 9% | 0 1 | 0 3 | 1 | 1 | | 0 1 | 0 3 | 2 |
| **Subtotals and averages** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Eden Landing | | | | 1.100 | 20 | 220.100 | | 99.000 | 55.600 | 33.000 | 21.900 | 10.500 | 99.000 | 55.600 | 65.400 | 60 | 160 | 14% | 5 | 8 | 33 | 45 | 65 | 5 | 8 | 143 |
| Alviso | | | | 1,322 | 18 | 237.800 | | 107 300 | 62.900 | 35.700 | 23.800 | 8.200 | 107.300 | 62.900 | 67.700 | 30 | 130 | 10% | 6 | 9 | 36 | 49 | 35 | 6 | 9 | 119 |
| Ravenswood | | | | 415 | 20 | 83.100 | | 37.300 | 21.000 | 12.400 | 8.300 | 3.800 | 37.300 | 21.000 | 24.500 | 50 | 60 | 15% | 2 | 3 | 12 | 17 | 26 | 2 | 3 | 55 |
| **Totals and averages** | | | | 2,837 | 19 | 541,000 | | 243,600 | 139,500 | 81,100 | 54,000 | 22,500 | 243,600 | 139,500 | 157,600 | 50 | 350 | 12% | 12 | 21 | 81 | 111 | 125 | 12 | 21 | 317 |

* Width of highest order channel is calculated and tabulated under Max channel width

**Appendix C.**

Table 2 Alternative B tidal channel and marsh panne estimates for the SBSP South Bay Geomorphic Assessment

| | | | | | **Marsh Panne Estimates**<br>by age of equilibrium (i.e. pickleweed or bulrush marshplain at MHHW) marsh | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Age: Young marsh | | | | | | | | | | | | Intermediate marsh | Mature marsh | | | | |
| | | | | | Panne type: Marshplain | | | | Foreshore | | | | Backshore | | | | | Marshplain | | | | Foreshore and backshore |
| Pond Complex | GIS Ponds ID | Marsh unit | Marsh type | Marsh unit area (ha) | Ave size (ha) | Density (#/ha) | % marsh area (ha/ha) | Area (ha) | Zone length (m) | Zone width (m) | % zone area (ha/ha) | Area (ha) | Zone length (m) | Zone width (m) | % zone area (ha/ha) | Area (ha) | | Ave size (ha) | Density (#/ha marsh) | % marsh area (ha/ha marsh) | Area (ha) | |
| Eden Landing | 95 | E6 | salt | 207 | 0 07 | 1 4 | 10% | 20 | | | | | 1 900 | 30 | 50% | 3 | Areas of foreshore and bachshore pannes are the same as for the Young marsh; no marshplain pannes | 0 04 | 0 5 | 2% | 4 | Areas of foreshore and bachshore pannes are the same as for the Young marsh |
| Eden Landing | 105 | E9 | salt | 148 | 0 07 | 1 4 | 10% | 14 | | | | | | | | | | 0 04 | 0 5 | 2% | 3 | |
| Eden Landing | 103 | E8A | salt | 107 | 0 07 | 1 4 | 10% | 11 | | | | | | | | | | 0 04 | 0 5 | 2% | 2 | |
| Eden Landing | 103 | E5C | salt | 142 | 0 07 | 1 4 | 10% | 14 | | | | | | | | | | 0 04 | 0 5 | 2% | 3 | |
| Eden Landing | 98 | E2 | salt | 272 | 0 07 | 1 4 | 10% | 27 | 1.300 | 100 | 50% | 7 | | | | | | 0 04 | 0 5 | 2% | 5 | |
| Eden Landing | 99 | E1 | salt | 169 | 0 07 | 1 4 | 10% | 17 | | | | | | | | | | 0 04 | 0 5 | 2% | 3 | |
| Eden Landing | 96 | E4 | salt | 54 | 0 07 | 1 4 | 10% | 5 | | | | | | | | | | 0.04 | 0 5 | 2% | 1 | |
| Alviso | 134 | A21 | brackish | 59 | 0 07 | 1 4 | 10% | 6 | | | | | | | | | | 0 2 | 0 4 | 8% | 5 | |
| Alviso | 138 | A19 | brackish | 107 | 0 07 | 1.4 | 10% | 11 | | | | | | | | | | 0 2 | 0.4 | 8% | 9 | |
| Alviso | 135 | A20 | brackish | 25 | 0 07 | 1.4 | 10% | 2 | | | | | | | | | | 0.2 | 0.4 | 8% | 2 | |
| Alviso | 139 | A8 | salt | 111 | 0 07 | 1.4 | 10% | 11 | | | | | | | | | | 0.04 | 0 5 | 2% | 2 | |
| Alviso | 139 | A8 | brackish | 111 | 0 07 | 1.4 | 10% | 11 | | | | | | | | | | 0.2 | 0 4 | 8% | 9 | |
| Alviso | 140 | A6-B | salt | 59 | 0 07 | 1 4 | 10% | 6 | | | | | | | | | | 0 04 | 0 5 | 2% | 1 | |
| Alviso | 147 | A7 | salt | 103 | 0 07 | 1 4 | 10% | 10 | | | | | | | | | | 0 04 | 0 5 | 2% | 2 | |
| Alviso | 146 | A5 | salt | 174 | 0 07 | 1 4 | 10% | 17 | | | | | | | | | | 0.04 | 0 5 | 2% | 3 | |
| Alviso | 146 | A5 | brackish | 75 | 0 07 | 1 4 | 10% | 7 | | | | | | | | | | 0 2 | 0 4 | 8% | 6 | |
| Alviso | 161 | A3N | salt | 37 | 0 07 | 1 4 | 10% | 4 | | | | | 200 | 30 | 50% | 0 3 | | 0 04 | 0 5 | 2% | 1 | |
| Alviso | 142 | A6-A | salt | 75 | 0 07 | 1.4 | 10% | 7 | | | | | | | | | | 0 04 | 0 5 | 2% | 1 | |
| Alviso | 166 | A1-B | salt | 85 | 0 07 | 1 4 | 10% | 8 | | | | | 800 | 30 | 50% | 1 | | 0 04 | 0 5 | 2% | 2 | |
| Alviso | 166 | A1-A | salt | 27 | 0 07 | 1.4 | 10% | 3 | | | | | | | | | | 0 04 | 0 5 | 2% | 1 | |
| Alviso | 165 | A2W-B | salt | 84 | 0 07 | 1 4 | 10% | 8 | | | | | 400 | 30 | 50% | 1 | | 0 04 | 0 5 | 2% | 2 | |
| Alviso | 165 | A2W-A | salt | 90 | 0 07 | 1.4 | 10% | 9 | | | | | 500 | 30 | 50% | 1 | | 0 04 | 0 5 | 2% | 2 | |
| Alviso | 164 | AB1 | salt | 56 | 0.07 | 1.4 | 10% | 6 | | | | | 600 | 30 | 50% | 1 | | 0 04 | 0 5 | 2% | 1 | |
| Alviso | 164 | AB2 | salt | 43 | 0 07 | 1 4 | 10% | 4 | | | | | 1.000 | 30 | 50% | 2 | | 0 04 | 0 5 | 2% | 1 | |
| Ravenswood | 8 | R4 | salt | 120 | 0 07 | 1 4 | 10% | 12 | 500 | 100 | 50% | 3 | 900 | 30 | 50% | 1 | | 0 04 | 0 5 | 2% | 2 | |
| Ravenswood | 10 | R1 | salt | 265 | 0 07 | 1 4 | 10% | 26 | 1.100 | 100 | 50% | 5 | 1.300 | 30 | 50% | 2 | | 0 04 | 0 5 | 2% | 5 | |
| Ravenswood | 227 | SF2 | salt | 30 | 0 07 | 1 4 | 10% | 3 | | | | | | | | | | 0 04 | 0 5 | 2% | 1 | |
| **Subtotals and averages** | | | | | | | | | | | | | | | | | | | | | | |
| Eden Landing | | | | 1.100 | 0 07 | 1.4 | 10% | 110 | 1.300 | 100 | 50% | 7 | 1,900 | 30 | 50% | 3 | | 0 04 | 0 5 | 2% | 20 | |
| Alviso | | | | 1,322 | 0 07 | 1.4 | 10% | 130 | | | | | 583 | 30 | 50% | 10 | | 0 09 | 0 5 | 4% | 50 | |
| Ravenswood | | | | 415 | 0 07 | 1 4 | 10% | 40 | 800 | 100 | 50% | 8 | 1.100 | 30 | 50% | 3 | | 0 04 | 0 5 | 2% | 10 | |
| **Totals and averages** | | | | 2,837 | 0.07 | 1.4 | 10% | 280 | 2,000 | 100 | 50% | 10 | 844 | 30 | 50% | 11 | | 0.06 | 0.5 | 3% | 80 | |

**Appendix C.**
Table 3 Alternative C tidal channel and marsh panne estimates for the SBSP South Bay Geomorphic Assessment

| | | | | | | | Tidal Channel Estimates | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Channel length (m) by channel order and average width | 1 | 2 | 3 | 4 | 5* | Channel length (m) by width class | | | | | | | | | | | Channel area (ha) by width class | | |
| Pond Complex | GIS Ponds ID | Marsh unit | Marsh type | Marsh unit area | Linear channel density | Length of channel | Ave salt marsh channel width (m): | 0 5 | 1 5 | 10 | 20" | | Small | Medium | Large | Max channel width | Channel area | | Channel area (ha) by channel order | | | | | Small | Medium | Large |
| | | | | (ha) | (km/km2) | (m) | Ave brackish marsh channel width (m): | 0.5 | 1.5 | 10 | 15* | | W < 0.6 m | 0.6 m < W < 4m | W > 4 m | (m) | (ha) | % marsh area (ha/ha) | 1 | 2 | 3 | 4 | 5 | W < 0.6 m | 0.6 m < W < 4 m | W > 4 m |
| Eden Landing | 95 | E6 | salt | 207 | 20 | 41.500 | | 18.700 | 10.400 | 6.200 | 4.100 | 2.100 | 18.700 | 10.400 | 12.400 | 70 | 31 | 15% | 0 9 | 1 6 | 6 | 8 | 14 | 0 9 | 1 6 | 28 |
| Eden Landing | 105 | E9 | salt | 211 | 20 | 42.200 | | 19,000 | 10.500 | 6.300 | 4.200 | 2.100 | 19,000 | 10.500 | 12,600 | 70 | 31 | 15% | 0 9 | 1 6 | 6 | 8 | 14 | 0 9 | 1 6 | 29 |
| Eden Landing | 103 | E8A | salt | 107 | 20 | 21.500 | | 9,700 | 5.400 | 3.200 | 2.100 | 1.100 | 9,700 | 5.400 | 6.400 | 50 | 14 | 13% | 0 5 | 0 8 | 3 | 4 | 5 | 0 5 | 0 8 | 12 |
| Eden Landing | 91 | E5C | salt | 142 | 20 | 28.400 | | 12.800 | 7,100 | 4.300 | 2.800 | 1.400 | 12.800 | 7,100 | 8,500 | 50 | 19 | 14% | 0 6 | 1 1 | 4 | 6 | 8 | 0 6 | 1.1 | 18 |
| Eden Landing | 98 | E2 | salt | 272 | 20 | 54.500 | | 24.500 | 13,600 | 8.200 | 5.400 | 2.700 | 24,500 | 13,600 | 16.300 | 80 | 43 | 16% | 1 2 | 2 | 8 | 11 | 21 | 1 2 | 2 | 40 |
| Eden Landing | 99 | E1 | salt | 169 | 20 | 33.900 | | 15.200 | 8.500 | 5.100 | 3.400 | 1.700 | 15.200 | 8.500 | 10,200 | 60 | 24 | 14% | 0 8 | 1 3 | 5 | 7 | 10 | 0 8 | 1 3 | 22 |
| Eden Landing | 100 | E6A | salt | 146 | 20 | 29.100 | | 13.100 | 7.300 | 4.400 | 2.900 | 1.500 | 13.100 | 7.300 | 8.800 | 50 | 20 | 14% | 0 7 | 1 1 | 4 | 6 | 8 | 0 7 | 1 1 | 18 |
| Eden Landing | 100 | E8 | salt | 191 | 20 | 38.200 | | 17,200 | 9.500 | 5.700 | 3.800 | 1.900 | 17,200 | 9.500 | 11,400 | 60 | 28 | 14% | 0 9 | 1 4 | 6 | 8 | 12 | 0 9 | 1 4 | 25 |
| Eden Landing | 96 | E4 | salt | 54 | 20 | 10.700 | | 4.800 | 3.200 | 1.600 | 1,100 | | 4.800 | 3.200 | 2.700 | 30 | 6 | 11% | 0 2 | 0 5 | 1 6 | 3 | | 0 2 | 0 5 | 5 |
| Alviso | 134 | A21 | brackish | 59 | 13 | 7.700 | | 3.500 | 2.300 | 1.200 | 800 | | 3.500 | 2.300 | 2,000 | 20 | 3 | 5% | 0 2 | 0 3 | 1 | 1 | | 0 2 | 0 3 | 3 |
| Alviso | 152 | A17 | brackish | 53 | 13 | 6,900 | | 3,100 | 2,100 | 1,000 | 700 | | 3.100 | 2,100 | 1,700 | 30 | 3 | 6% | 0 2 | 0 3 | 1 | 2 | | 0 2 | 0 3 | 3 |
| Alviso | 155 | A15 | salt | 347 | 20 | 69.400 | | 31,300 | 17,400 | 10,400 | 6.900 | 3.500 | 31,300 | 17,400 | 20.800 | 90 | 59 | 17% | 1 6 | 2 6 | 10 | 14 | 30 | 1 6 | 2 6 | 55 |
| Alviso | 157 | A11 | salt | 106 | 20 | 21.300 | | 9.600 | 5.300 | 3.200 | 2.100 | 1.100 | 9.600 | 5.300 | 6.400 | 50 | 14 | 13% | 0 5 | 0 8 | 3 | 4 | 5 | 0 5 | 0 8 | 12 |
| Alviso | 138 | A19 | brackish | 107 | 13 | 13.900 | | 6.300 | 4.200 | 2,100 | 1,400 | | 6.300 | 4.200 | 3,500 | 30 | 6 | 6% | 0 3 | 0 6 | 2 | 3 | | 0 3 | 0 6 | 5 |
| Alviso | 135 | A20 | brackish | 25 | 13 | 3.300 | | 1.500 | 1.000 | 500 | 300 | | 1.500 | 1.000 | 800 | 20 | 1 | 5% | 0 1 | 0 1 | 1 | 1 | | 0 1 | 0 1 | 1 |
| Alviso | 145 | A12 | salt | 125 | 20 | 25,000 | | 11.300 | 6.300 | 3.800 | 2.500 | 1,300 | 11.300 | 6.300 | 7,600 | 50 | 16 | 13% | 0 6 | 0 9 | 4 | 5 | 6 | 0 6 | 0 9 | 15 |
| Alviso | 139 | A8 | salt | 111 | 20 | 22.200 | | 10,000 | 5.600 | 3.300 | 2.200 | 1,100 | 10,000 | 5.600 | 6.600 | 50 | 14 | 13% | 0 5 | 0 8 | 3 | 4 | 5 | 0 5 | 0 8 | 13 |
| Alviso | 139 | A8 | brackish | 111 | 13 | 14.400 | | 6.500 | 3.600 | 2.200 | 1,400 | 700 | 6.500 | 3.600 | 4,300 | 50 | 8 | 7% | 0 3 | 0 5 | 2 | 2 | 3 | 0 3 | 0 5 | 8 |
| Alviso | 137 | A22 | brackish | 57 | 13 | 7.400 | | 3,300 | 2.200 | 1.100 | 700 | | 3,300 | 2.200 | 1.800 | 30 | 3 | 6% | 0 2 | 0 3 | 1 | 2 | | 0 2 | 0 3 | 3 |
| Alviso | 137 | A23 | brackish | 232 | 13 | 30.200 | | 13.600 | 7.500 | 4.500 | 3.000 | 1.500 | 13.600 | 7.500 | 9.000 | 70 | 20 | 9% | 0 7 | 1 1 | 5 | 5 | 10 | 0 7 | 1 1 | 19 |
| Alviso | 159 | A9 | salt | 148 | 20 | 29.500 | | 13,300 | 7.400 | 4.400 | 3.000 | 1.500 | 13,300 | 7,400 | 8,900 | 50 | 20 | 14% | 0 7 | 1 1 | 4 | 6 | 8 | 0 7 | 1 1 | 18 |
| Alviso | 140 | A6-B | salt | 59 | 20 | 11.800 | | 5.300 | 3.500 | 1.800 | 1.200 | | 5.300 | 3.500 | 3.000 | 30 | 6 | 11% | 0 3 | 0 5 | 2 | 4 | | 0 3 | 0 5 | 6 |
| Alviso | 158 | A10 | salt | 101 | 20 | 20.100 | | 9.100 | 5.000 | 3.000 | 2.000 | 1.000 | 9.100 | 5.000 | 6.000 | 40 | 13 | 13% | 0 5 | 0 8 | 3 | 4 | 4 | 0 5 | 0 8 | 11 |
| Alviso | 147 | A7 | salt | 103 | 20 | 20.700 | | 9,300 | 5.200 | 3.100 | 2.100 | 1.000 | 9,300 | 5.200 | 6,200 | 40 | 13 | 13% | 0 5 | 0 8 | 3 | 4 | 5 | 0 5 | 0 8 | 12 |
| Alviso | 146 | A5 | salt | 174 | 20 | 34.800 | | 15.700 | 8.700 | 5.200 | 3.500 | 1,700 | 15.700 | 8.700 | 10,400 | 40 | 21 | 12% | 0 8 | 1 3 | 5 | 7 | 7 | 0 8 | 1 3 | 19 |
| Alviso | 146 | A5 | brackish | 75 | 13 | 9.700 | | 4.400 | 2.400 | 1.500 | 1,000 | 500 | 4.400 | 2.400 | 3.000 | 40 | 5 | 7% | 0 2 | 0.4 | 2 | 2 | 2 | 0 2 | 0 4 | 5 |
| Alviso | 161 | A3N | salt | 37 | 20 | 7.400 | | 3.300 | 2.200 | 1.100 | 700 | | 3.300 | 2.200 | 1.800 | 30 | 3 | 9% | 0 2 | 0 3 | 1 | 2 | | 0 2 | 0 3 | 3 |
| Alviso | 142 | A6-A | salt | 75 | 20 | 15,000 | | 6.700 | 3.700 | 2.200 | 1.500 | 700 | 6.700 | 3.700 | 4.400 | 40 | 9 | 12% | 0 3 | 0 6 | 2 | 3 | 3 | 0 3 | 0 6 | 8 |
| Alviso | 166 | A1-B | salt | 85 | 20 | 16,900 | | 7.600 | 4.200 | 2,500 | 1,700 | 800 | 7.600 | 4.200 | 5.000 | 40 | 10 | 12% | 0 4 | 0 6 | 3 | 3 | 3 | 0 4 | 0 6 | 9 |
| Alviso | 166 | A1-A | salt | 27 | 20 | 5.500 | | 2.500 | 1.600 | 800 | 500 | | 2.500 | 1.600 | 1.300 | 20 | 2 | 9% | 0 1 | 0 2 | 1 | 1 | | 0 1 | 0 2 | 2 |
| Alviso | 165 | A2W-B | salt | 84 | 20 | 16.800 | | 7.600 | 4.200 | 2.500 | 1.700 | 800 | 7.600 | 4.200 | 5.000 | 40 | 10 | 12% | 0 4 | 0 6 | 3 | 3 | 3 | 0 4 | 0 6 | 9 |
| Alviso | 165 | A2W-A | salt | 90 | 20 | 17.900 | | 8,100 | 4.500 | 2,700 | 1.800 | 900 | 8,100 | 4.500 | 5.400 | 40 | 11 | 12% | 0 4 | 0 7 | 3 | 4 | 4 | 0 4 | 0 7 | 10 |
| Alviso | 164 | AB1 | salt | 130 | 20 | 26.100 | | 11,700 | 6.500 | 3.900 | 2.600 | 1,300 | 11,700 | 6.500 | 7.800 | 50 | 17 | 13% | 0 6 | 1 | 4 | 5 | 7 | 0 6 | 1 | 16 |
| Alviso | 164 | AB2 | salt | 83 | 20 | 16.600 | | 7,500 | 4.100 | 2.500 | 1.700 | 800 | 7,500 | 4.100 | 5.000 | 40 | 10 | 12% | 0 4 | 0 6 | 3 | 3 | 3 | 0 4 | 0 6 | 9 |
| Ravenswood | 8 | R4 | salt | 120 | 20 | 24.100 | | 10.800 | 6,000 | 3.600 | 2.400 | 1.200 | 10.800 | 6,000 | 7,200 | 50 | 16 | 13% | 0 5 | 0.9 | 4 | 5 | 6 | 0 5 | 0 9 | 14 |
| Ravenswood | 10 | R1 | salt | 265 | 20 | 53.000 | | 23,800 | 13,200 | 7,900 | 5,300 | 2.600 | 23,800 | 13,200 | 15,800 | 70 | 42 | 16% | 1 2 | 2 | 8 | 11 | 20 | 1 2 | 2 | 38 |
| Ravenswood | 227 | SF2 | salt | 30 | 20 | 6.000 | | 2.700 | 1.800 | 900 | 600 | | 2.700 | 1.800 | 1.500 | 20 | 3 | 9% | 0.1 | 0 3 | 1 | 1 | | 0 1 | 0 3 | 2 |
| Ravenswood | 7 | R3-A | salt | 87 | 20 | 17.400 | | 7.800 | 4.400 | 2,600 | 1,700 | 900 | 7.800 | 4.400 | 5.200 | 40 | 11 | 12% | 0 4 | 0 7 | 3 | 4 | 4 | 0 4 | 0 7 | 10 |
| Ravenswood | 7 | R3-B | salt | 23 | 20 | 4.600 | | 2.100 | 1.400 | 700 | 500 | | 2.100 | 1.400 | 1.200 | 20 | 2 | 8% | 0 1 | 0 2 | 1 | 1 | | 0 1 | 0 2 | 2 |
| **Subtotals and averages** | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Eden Landing | | | | 1.499 | 20 | 300.000 | | 135.000 | 75.500 | 45.000 | 29.800 | 14.500 | 135.000 | 75.500 | 89.300 | 60 | 220 | 14% | 7 | 11 | 45 | 61 | 90 | 7 | 11 | 196 |
| Alviso | | | | 2,606 | 18 | 470.500 | | 212.100 | 120.700 | 70 500 | 47.000 | 20.200 | 212.100 | 120.700 | 137 700 | 40 | 300 | 11% | 11 | 18 | 71 | 94 | 108 | 11 | 18 | 273 |
| Ravenswood | | | | 526 | 20 | 105.100 | | 47.200 | 26.800 | 15.700 | 10.500 | 4.700 | 47.200 | 26 800 | 30.900 | 40 | 70 | 14% | 2 | 4 | 16 | 21 | 29 | 2 | 4 | 66 |
| **Totals and averages** | | | | 4,631 | 19 | 875,600 | | 394,300 | 223,000 | 131,200 | 87,300 | 39,400 | 394,300 | 223,000 | 257,900 | 50 | 590 | 13% | 20 | 33 | 131 | 176 | 227 | 20 | 33 | 535 |

* Width of highest order channel is calculated and tabulated under Max channel width

**Appendix C.**
Table 3 Alternative C tidal channel and marsh panne estimates for the SBSP South Bay Geomorphic Assessment

| | | | | | Marsh Panne Estimates<br>by age of equilibrium (i.e. pickleweed or bulrush marshplain at MHHW) marsh | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Age: | Young marsh | | | | | | | | | | | | Intermediate marsh | Mature marsh | | | | |
| | | | | type: | Marshplain | | | | Foreshore | | | | Backshore | | | | | Marshplain | | | | backshore |
| Pond Complex | GIS Ponds ID | Marsh unit | Marsh type | Marsh unit area | Ave size | Density | % marsh area | Area | Zone length | Zone width | % zone area | Area | Zone length | Zone width | % zone area | Area | | Ave size | Density (#/ha marsh) | % marsh area (ha/ha marsh) | Area | |
| | | | | (ha) | (ha) | (#/ha) | (ha/ha) | (ha) | (m) | (m) | (ha/ha) | (ha) | (m) | (m) | (ha/ha) | (ha) | | (ha) | | | (ha) | |
| Eden Landing | 95 | E6 | salt | 207 | 0 07 | 1 4 | 10% | 20 | | | | | 1.900 | 30 | 50% | 3 | Areas of foreshore and bachshore pannes are the same as for the Young marsh; no marshplain pannes | 0.04 | 0 5 | 2% | 4 | Areas of foreshore and bachshore pannes are the same as for the Young marsh |
| Eden Landing | 105 | E9 | salt | 211 | 0 07 | 1 4 | 10% | 21 | | | | | | | | | | 0 04 | 0 5 | 2% | 4 | |
| Eden Landing | 103 | E8A | salt | 107 | 0 07 | 1 4 | 10% | 11 | | | | | | | | | | 0 04 | 0 5 | 2% | 2 | |
| Eden Landing | 91 | E5C | salt | 142 | 0 07 | 1 4 | 10% | 14 | | | | | 1.300 | 30 | 50% | 2 | | 0 04 | 0 5 | 2% | 3 | |
| Eden Landing | 98 | E2 | salt | 272 | 0 07 | 1 4 | 10% | 27 | 1.300 | 100 | 50% | 7 | | | | | | 0 04 | 0 5 | 2% | 5 | |
| Eden Landing | 99 | E1 | salt | 169 | 0 07 | 1 4 | 10% | 17 | | | | | | | | | | 0 04 | 0 5 | 2% | 3 | |
| Eden Landing | 100 | E6A | salt | 146 | 0 07 | 1 4 | 10% | 14 | | | | | 800 | 30 | 50% | 1 | | 0 04 | 0 5 | 2% | 3 | |
| Eden Landing | 100 | E8 | salt | 191 | 0 07 | 1 4 | 10% | 19 | | | | | 800 | 30 | 50% | 1 | | 0 04 | 0 5 | 2% | 4 | |
| Eden Landing | 96 | E4 | salt | 54 | 0 07 | 1 4 | 10% | 5 | | | | | | | | | | 0 04 | 0 5 | 2% | 1 | |
| Alviso | 134 | A21 | brackish | 59 | 0 07 | 1 4 | 10% | 6 | | | | | | | | | | 0 2 | 0 4 | 8% | 5 | |
| Alviso | 152 | A17 | brackish | 53 | 0 07 | 1 4 | 10% | 5 | | | | | | | | | | 0 2 | 0 4 | 8% | 4 | |
| Alviso | 155 | A15 | salt | 347 | 0 07 | 1 4 | 10% | 34 | | | | | | | | | | 0 04 | 0 5 | 2% | 7 | |
| Alviso | 157 | A11 | salt | 106 | 0 07 | 1 4 | 10% | 10 | | | | | | | | | | 0 04 | 0 5 | 2% | 2 | |
| Alviso | 138 | A19 | brackish | 107 | 0 07 | 1 4 | 10% | 11 | | | | | | | | | | 0 2 | 0 4 | 8% | 9 | |
| Alviso | 135 | A20 | brackish | 25 | 0 07 | 1 4 | 10% | 2 | | | | | | | | | | 0 2 | 0 4 | 8% | 2 | |
| Alviso | 145 | A12 | salt | 125 | 0 07 | 1 4 | 10% | 12 | | | | | | | | | | 0 04 | 0 5 | 2% | 3 | |
| Alviso | 139 | A8 | salt | 111 | 0 07 | 1 4 | 10% | 11 | | | | | | | | | | 0 04 | 0 5 | 2% | 2 | |
| Alviso | 139 | A8 | brackish | 111 | 0 07 | 1 4 | 10% | 11 | | | | | | | | | | 0 2 | 0 4 | 8% | 9 | |
| Alviso | 137 | A22 | brackish | 57 | 0 07 | 1 4 | 10% | 6 | | | | | 500 | 30 | 50% | 1 | | 0 2 | 0 4 | 8% | 5 | |
| Alviso | 137 | A23 | brackish | 232 | 0 07 | 1 4 | 10% | 23 | | | | | 1.000 | 30 | 50% | 2 | | 0 2 | 0 4 | 8% | 19 | |
| Alviso | 159 | A9 | salt | 148 | 0 07 | 1 4 | 10% | 14 | | | | | | | | | | 0 04 | 0 5 | 2% | 3 | |
| Alviso | 140 | A6-B | salt | 59 | 0 07 | 1 4 | 10% | 6 | | | | | | | | | | 0 04 | 0 5 | 2% | 1 | |
| Alviso | 158 | A10 | salt | 101 | 0 07 | 1 4 | 10% | 10 | | | | | | | | | | 0 04 | 0 5 | 2% | 2 | |
| Alviso | 147 | A7 | salt | 103 | 0 07 | 1 4 | 10% | 10 | | | | | | | | | | 0 04 | 0 5 | 2% | 2 | |
| Alviso | 146 | A5 | salt | 174 | 0 07 | 1 4 | 10% | 17 | | | | | | | | | | 0 04 | 0 5 | 2% | 3 | |
| Alviso | 146 | A5 | brackish | 75 | 0 07 | 1 4 | 10% | 7 | | | | | | | | | | 0 2 | 0 4 | 8% | 6 | |
| Alviso | 161 | A3N | salt | 37 | 0 07 | 1 4 | 10% | 4 | | | | | 200 | 30 | 50% | 0 3 | | 0 04 | 0 5 | 2% | 1 | |
| Alviso | 142 | A6-A | salt | 75 | 0 07 | 1 4 | 10% | 7 | | | | | | | | | | 0 04 | 0 5 | 2% | 1 | |
| Alviso | 166 | A1-B | salt | 85 | 0 07 | 1 4 | 10% | 8 | | | | | 800 | 30 | 50% | 1 | | 0 04 | 0 5 | 2% | 2 | |
| Alviso | 166 | A1-A | salt | 27 | 0 07 | 1 4 | 10% | 3 | | | | | | | | | | 0 04 | 0 5 | 2% | 1 | |
| Alviso | 165 | A2W-B | salt | 84 | 0 07 | 1 4 | 10% | 8 | | | | | 400 | 30 | 50% | 1 | | 0 04 | 0 5 | 2% | 2 | |
| Alviso | 165 | A2W-A | salt | 90 | 0 07 | 1 4 | 10% | 9 | | | | | 500 | 30 | 50% | 1 | | 0 04 | 0 5 | 2% | 2 | |
| Alviso | 164 | AB1 | salt | 130 | 0 07 | 1 4 | 10% | 13 | | | | | 600 | 30 | 50% | 1 | | 0 04 | 0 5 | 2% | 3 | |
| Alviso | 164 | AB2 | salt | 83 | 0 07 | 1 4 | 10% | 8 | | | | | 1.000 | 30 | 50% | 2 | | 0 04 | 0 5 | 2% | 2 | |
| Ravenswood | 8 | R4 | salt | 120 | 0 07 | 1 4 | 10% | 12 | 500 | 100 | 50% | 3 | 900 | 30 | 50% | 1 | | 0 04 | 0 5 | 2% | 2 | |
| Ravenswood | 10 | R1 | salt | 265 | 0 07 | 1 4 | 10% | 26 | 1.100 | 100 | 50% | 5 | 1.300 | 30 | 50% | 2 | | 0 04 | 0 5 | 2% | 5 | |
| Ravenswood | 227 | SF2 | salt | 30 | 0 07 | 1 4 | 10% | 3 | | | | | | | | | | 0 04 | 0.5 | 2% | 1 | |
| Ravenswood | 7 | R3-A | salt | 87 | 0 07 | 1 4 | 10% | 9 | | | | | | | | | | 0 04 | 0 5 | 2% | 2 | |
| Ravenswood | 7 | R3-B | salt | 23 | 0 07 | 1 4 | 10% | 2 | | | | | | | | | | 0 04 | 0 5 | 2% | 0 5 | |
| **Subtotals and averages** | | | | | | | | | | | | | | | | | | | | | | |
| Eden Landing | | | | 1.499 | 0 07 | 1 4 | 10% | 150 | 1.300 | 100 | 50% | 7 | 967 | 30 | 50% | 4 | | 0 04 | 0 5 | 2% | 30 | |
| Alviso | | | | 2,606 | 0 07 | 1 4 | 10% | 260 | | | | | 625 | 30 | 50% | 10 | | 0 09 | 0 5 | 4% | 100 | |
| Ravenswood | | | | 526 | 0 07 | 1 4 | 10% | 50 | 800 | 100 | 50% | 8 | 1.100 | 30 | 50% | 3 | | 0 04 | 0 5 | 2% | 10 | |
| **Totals and averages** | | | | 4,631 | 0.07 | 1.4 | 10% | 460 | 2,000 | 100 | 50% | 10 | 3,000 | 30 | 50% | 20 | | 0.06 | 0.5 | 3% | 140 | |