6. EVALUATION OF EXPANDED WETLANDS SIZES

6.1 GEOMETRY OF EXPANDED WETLANDS

The frequency of closure was analyzed for expanded wetland sizes using the calibrated QCM, and required the geometry of these hypothetical cases to be defined. Since the model uses an estimate of the effective tidal prism in computing inlet stability, the stage-storage relationship and low water drainage elevation must be established for each wetland size analyzed. The former depends on the shape and size of the lagoon, while monitoring data presented earlier show that the latter is governed by morphology of the inlet channel. The paragraphs below describe how each of these parameters was established for input to the QCM.

6.1.1 Expanded Lagoon Geometry

Although sedimentation over the tidal shoals and migration of the inlet channel was rapid following tidal restoration, the site currently appears to be in a dynamic equilibrium as a sandy coastal lagoon and in a transitional state as it evolves more slowly into a vegetated marsh. Therefore, the expanded wetland sizes were assumed to have the same distribution of sub- and inter-tidal areas as the existing lagoon, since an expanded site would likely induce short-term and rapid adjustments until a similar distribution of habitat is achieved (the time scale associated with evolution of a mature vegetated marsh is much longer.). This assumption allowed for a simple scaling of the existing storage capacity of the lagoon. For example, it was assumed that a wetland twice the size of the existing lagoon would have a basin area of 28 acres at MHHW (the current lagoon has an approximate footprint of 14 acres at MHHW) and twice the area at lower elevations within the tide range.

Although ecological values could possibly be enhanced by creating an expanded wetland with gentler side slopes – resulting in a larger footprint for the same tidal prism – project constraints have previously limited the area available for tidal restoration and resulted in the relatively steep side slopes in the existing Crissy Field tidal marsh. For the sake of consistency, this study assumes that expanded wetlands will have the same stage-storage characteristics as the existing Crissy Field marsh (i.e. the ratio of tidal prism to marsh area has been kept constant). The actual design characteristics of any expanded Crissy Field tidal marsh will be determined in a subsequent planning process to be conducted by the Trust, NPS, and Parks Conservancy.

The long-term morphology is likely to change the stage-storage characteristics of the constructed lagoon. However, monitoring data collected during the first few years (PWA, 2001a; 2001b) show very little deposition of estuarine sediments, and we expect tidal inlet processes to govern for at least the next couple of decades. The evolution of the lagoon is discussed in more detail later in this report.

6.1.2 Low Water Drainage of Expanded Wetlands

The effective tidal prism in the lagoon is strongly influenced by the amount of muting at the inlet. For example, the effective diurnal tidal prism of the existing 14-acre lagoon would increase from approximately 17 ac-ft to about 46 ac-ft if the inlet did not affect the tide range in the lagoon. Tidal prism is plotted against low water elevation in the lagoon for the existing and expanded wetland sizes in Figure 6-1. Monitoring data reveal that muting is a result of elevated low water levels in the lagoon, with no appreciable difference in high water levels. Therefore, a reasonable estimate of low water elevation for enlarged wetland size must be established before the QCM can be applied to these hypothetical cases. Since the maximum thalweg elevation of the inlet channel controls the low water elevation in the lagoon, we outline an approach below to estimate the amount of downcutting at the inlet throat and use this as a surrogate for changes in the lagoon low water elevation.

Channel depth is expected to increase with the size of the wetland, in response to greater tidal prism and an increase in tidal currents in the inlet channel. As described by Dean and Dalrymple (2002), changes in the equilibrium cross-sectional area at the inlet throat produced by increases in tidal prism may be estimated by differentiating tidal prism relationships. In the present study, the relationship proposed by Hughes (2002) based on equilibrium discharge and scour depth was applied to Crissy Field. The cross-sectional area of the inlet channel, A_e, is related to the effective tidal prism by:

$$A_e = 0.65 k_a \, (C_I P)^{8/9}$$

where

$$C_I = \frac{W^{1/8}}{\left[g(S_S - 1)\right]^{1/2} d_e^{3/8} T}$$

W is the inlet width at mean tide level, T is the tidal period, d_e is the median grain size, g gravitational acceleration, k_a is an empirical coefficient (with a best-fit value of 1.34), and P is the effective tidal prism.

Changes in the predicted cross-sectional area may be found by differentiating the equilibrium expression and multiplying by the change in tidal prism:

$$dA_e = \frac{\partial A_e}{\partial P} dP = \left[0.58 C_I P^{-1/9}\right] dP$$

here dA_e and dP are changes in cross-sectional area and tidal prism, respectively. The above equation was used to determine the changes in equilibrium cross-sectional area of the inlet throat. Due to the strong damping of the tide signal by the inlet, the above tidal prism relationship is applied to the cross-sectional area below the lagoon mean tide level (MTL_{lagoon}). Figure 6–2 shows, at a conceptual level, how the tidal prism relationship above was applied at Crissy Field. Agreement between the measured and predicted values of cross-sectional area is good, as shown in Figure 6–3, giving confidence in the application of the above tidal prism relationship.

Assuming that the width-to-depth ratio of the inlet throat remains the same, changes in depth of the throat can be estimated from:

$$\frac{h_{new}}{h_{old}} = \sqrt{\frac{A_{e\,new}}{A_{e\,old}}}$$

where h is the maximum depth at the throat, measured below MTL_{lagoon}. For the purposes of the present study, the amount of downcutting ($dh = h_{new} - h_{old}$) at the throat is assumed to extend to the thalweg as it crosses the flood shoal. This approach was applied for a range of wetland size and results are summarized in Table 6-1, along with the estimated effective tidal prisms. Although the effective tidal prisms plotted in Figure 6-1 are computed over a range of water levels, the estimated values of lagoon low water elevations are restricted to the upper half of the bay tide range and limit the effective tidal prism.

Table 6-1. Estimated Low Water Elevation and Tidal Prism of Expanded Wetland Sizes

Wetted Area at MHHW (acres)	Estimated Lagoon Low Water Elevation (ft NGVD)	Estimated Effective Mean Diurnal Tidal Prism (ac-ft)
14	% 1.50	17
18	% 1.28	24
21	% 1.08	31
25	% 0.89	39
28	% 0.72	47
32	% 0.57	56

6.2 CLOSURE POTENTIAL OF EXPANDED WETLAND SIZES

The calibrated QCM described above was applied to various expanded wetland sizes in order to determine the minimum size required to maintain continuous tidal action. The frequency of closure for intermediate wetland sizes was also established in order to assess the level of maintenance required if project constraints limited future expansions of the lagoon at Crissy Field to a footprint smaller than that required to naturally maintain tidal action. All of these various wetland sizes were analyzed by simulating inlet stability from 12/06/1996 to 09/30/2002, the period over which historical weave and tidal data were available and after dynamic equilibrium was achieved.

6.2.1 Minimum Wetland Size

Stage-storage curves representative of expanded wetland sizes were applied to the QCM until no closures were predicted over the simulation period. Through a trial and error approach, we determined the minimum wetland size required to naturally maintain continuous tidal action over this period to be about

32 acres, approximately 2¼ times its existing size. About 0.93 ft of downcutting is expected for this size of wetland, resulting in low water elevation of about +0.57 ft NGVD and an effective tidal prism of approximately 56 ac-ft.

6.2.1.1 Model Sensitivity

Natural systems exhibit a tremendous amount of variability, especially systems as dynamic as small tidal inlets. For example, cross-sectional areas of inlet channels can vary significantly during a single tidal cycle and between spring and neap tides (Goodwin and Williams, 1991; DeTemple, Battalio, and Kulpa, 1999). Therefore, the equilibrium areas predicted by tidal prism relationships should be interpreted as nominal time-averaged values. Since these predictions were used in the present study to estimate the low water elevations in expanded wetlands, a sensitivity analysis was carried out to assess the importance of these uncertainties.

Sensitivity runs were carried out for the 32-acre lagoon by varying the low water elevation. A reduced amount of downcutting was assumed, and the same stage-storage curve was applied to the QCM. We ran simulations assuming the low water in the lagoon dropped by only 0.62 ft and 0.31 ft, instead of the estimate 0.93 ft. Results from these QCM sensitivity runs are summarized in Tables 6-2 and 6-3, and illustrate how sensitive closure frequency is to the amount of downcutting along the thalweg of the inlet channel. The intermediate downcutting value of 0.62 ft resulted in very infrequent closures. The QCM model predicted only three closures over the six-year simulation period for these conditions, all of which naturally re-opened in less than eight days. The most conservative estimate, in which low water elevations in the lagoon dropped by only 0.31 ft, lead to fourteen closures (about 2.4 closures per year). Four of these events spanned more than 14 days and required intervention to re-establish tidal action.

Table 6-2. Simulated Closures for 32-acre Marsh and 0.62 ft of Downcutting

Closure	Dates		Days	Index	Wave Power	Tidal Power	HH-1	HH-2	Berm	Breach
1	4/9/1999	4/16/1999	6.8	20.7	885.6	42.8	2.00	3.64	3.42	Nat
2	5/9/1999	5/13/1999	4.1	12.4	475.4	38.4	1.80	3.27	3.09	Nat
3	4/26/2000	5/3/2000	7.3	12.3	663.2	54.0	1.54	3.43	3.21	Nat

Table 6-3. Simulated Closures for 32-acre Marsh and 0.31 ft of Downcutting

Closure	Dates		Days	Index	Wave Power	Tidal Power	HH-1	HH-2	Berm	Breach
1	4/19/1999	4/23/1999	3.7	14.9	1183.8	79.6	1.89	3.36	3.30	Nat
2	11/26/1998	11/29/1998	3.1	12.1	1561.9	129.3	2.30	4.66	3.99	Nat
3	12/9/1998	12/23/1998	14.0	12.2	1255.4	102.8	2.08	2.21	4.28	Mech
4	4/9/1999	4/16/1999	6.8	12.2	885.6	72.8	2.00	3.64	3.43	Nat
5	5/9/1999	5/13/1999	4.1	24.7	475.4	19.3	1.80	3.27	3.08	Nat

Closure	Dates		Days	Index	Wave Power	Tidal Power	HH-1	HH-2	Berm	Breach
6	12/13/1999	12/18/1999	5.1	15.9	518.2	32.6	1.65	3.50	3.05	Nat
7	3/29/2000	4/5/2000	6.1	17.9	793.1	44.2	1.85	3.23	3.23	Nat
8	4/24/2000	5/3/2000	8.8	12.3	753.1	61.5	1.69	3.43	3.34	Nat
9	12/2/2000	12/7/2000	5.0	12.1	834.0	69.2	2.11	3.55	3.48	Nat
10	1/29/2001	2/4/2001	5.3	12.2	1055.2	86.2	1.85	3.62	3.44	Nat
11	4/16/2001	4/30/2001	14.0	12.0	315.9	26.2	1.67	2.00	3.40	Mech
12	5/2/2001	5/16/2001	14.0	12.2	916.9	75.1	2.28	2.24	3.79	Mech
13	10/24/2001	11/5/2001	11.5	12.0	681.7	56.6	1.98	3.27	3.62	no data
14	11/21/2001	12/5/2001	14.0	12.3	2586.5	210.8	2.34	2.92	5.42	Mech

6.2.2 Intermediate Wetland Sizes

Wetland size between the existing 14 acres and minimum footprint of 32 acres were analyzed in order to predict the number of closure/breach events and to estimate the level of maintenance required to maintain adequate tidal functions (defined for purposes of this model as closures less than 14 days). Table 6-4 presents results from the QCM for these intermediate wetland sizes. As noted earlier, variability in the natural system and the approximate nature of the analysis should be considered when interpreting these results. Although the information in Table 6-4 clearly shows a relationship between wetland size and inlet performance, it is worth while to note the exact geometry of an enlarged wetland may influence the amount of potential tidal prism mobilized to maintain the inlet.

The need for mechanical intervention may be reduced slightly if the model were changed to allow for longer closures (i.e., greater than14 days). However, for the marsh sizes simulated, we do not expect the number of mechanical breaches required to vary significantly. Although longer closure durations could provide more opportunity of overtopping of the beach barrier during unusually high tides or other events, most of the variation in the tides is captured over a 14-day period. It is important to note that the acceptable duration of inlet closure may vary depending on the results of continued ecological monitoring conducted by the NPS.

Table 6-4. Simulated Closures for Intermediate Wetland Sizes During 6-Year Simulation

Tidal Prism* (ac-ft)	Wetted area at MHHW	Reduction in Low Water Elevation (ft)	Number of Closures/Breaches				
			Natural Breaching	Mechanical Breaching	Total	Closures/year	Mechanical Breaching /year
17	14	-	18	12	30	5.2	2.1
24	18	0.22	12	10	22	3.8	1.7
31	21	0.42	11	4	15	2.6	0.7
39	25	0.61	4	1	5	0.9	0.1
47	28	0.78	2	0	2	0.1	0.0
56	32	0.93	0	0	0	0.0	0.0

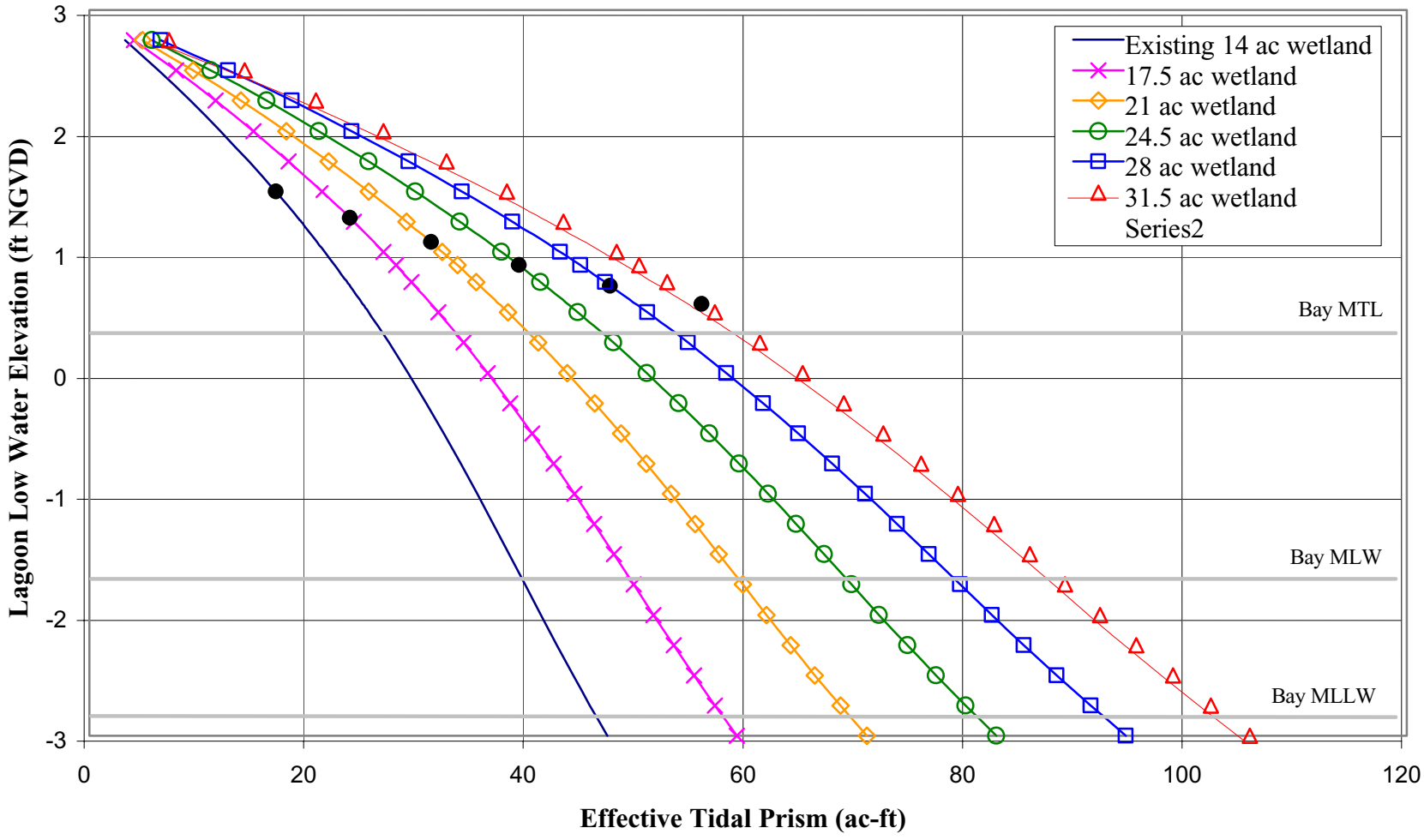
* Assumes same stage/storage characteristics as existing marsh. Simulation period is from 12/06/1996 to 09/30/2002.

6.3 EVOLUTION OF THE CONSTRUCTED WETLAND

We expect the constructed wetland to ultimately mature into a vegetated marsh and most of the remaining sub-tidal habitat to be restricted to a few tidal channels. However, observed sedimentation rates of cohesive material are very low, and the site is likely to continue functioning as a sandy coastal lagoon for at least the next several decades, with its tidal functions primarily influenced by inlet morphology and dynamics.

Figure 6–4 shows the expected siltation due to estuarine sediments over the long-term. Following several decades during which the mash maintains its existing condition, the sub-tidal and lower inter-tidal sandflats/mudflats will dimension in favor of higher inter-tidal marsh. The overall effect of sedimentation is a significant reduction in the tidal prism. The amount of high marsh at Crissy Field may be less than other sites in San Francisco Bay due to the steady wind that will generate local wind-waves in the lagoon that may slow, and perhaps halt, sedimentation in some locations higher than sandflat/mudflat elevation.

Although a large portion of the presently open water lagoon will eventually fill in with sediment after several decades, the effective tidal range is expected to increase due to the cohesive properties of estuarine mud. For example, based on hydraulic geometry relationships for mature marshes in San Francisco Bay, a 32-acre marsh would develop an entrance channel about 7 ft below MHHW. The presence of large waves, relative to other marshes in San Francisco Bay, and the strong littoral drift may limit the depth of the entrance channel. For the purposes of examining the closure potential for an evolved 32-acre marsh, we assumed the entrance channel thalweg elevation was at mean low water (–1.75 ft NGVD), or about 4.7 ft below MHHW.



Notes: Black dots denotes estimated low water drainage elevation for given wetland size. Volumes calculated from stage storage curves extrapolated from 2002 data.

figure 6-1

Crissy Field Marsh Expansion Study

Tidal Prisms of Expanded Wetlands

PWA#: 1623

PWA

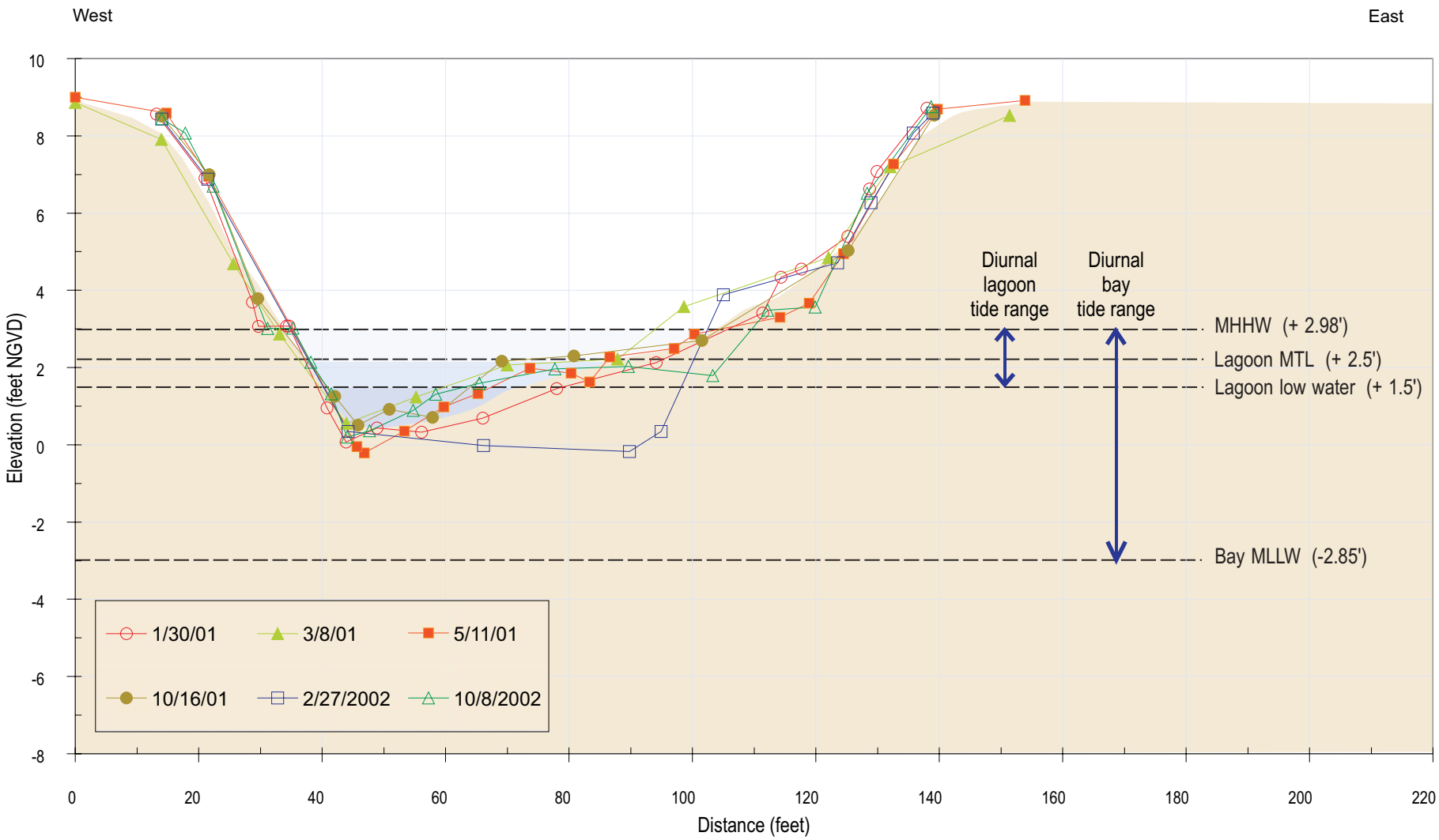


figure 6-2

Crissy Field Expansion Study

Cross-Sectional Area at Inlet Throat and Tide Levels

Note: Cross section area below lagoon MTL used in tidal prism relationship

PWA#: 1623.10 Section 6 Entrance Channel.cdr PWA

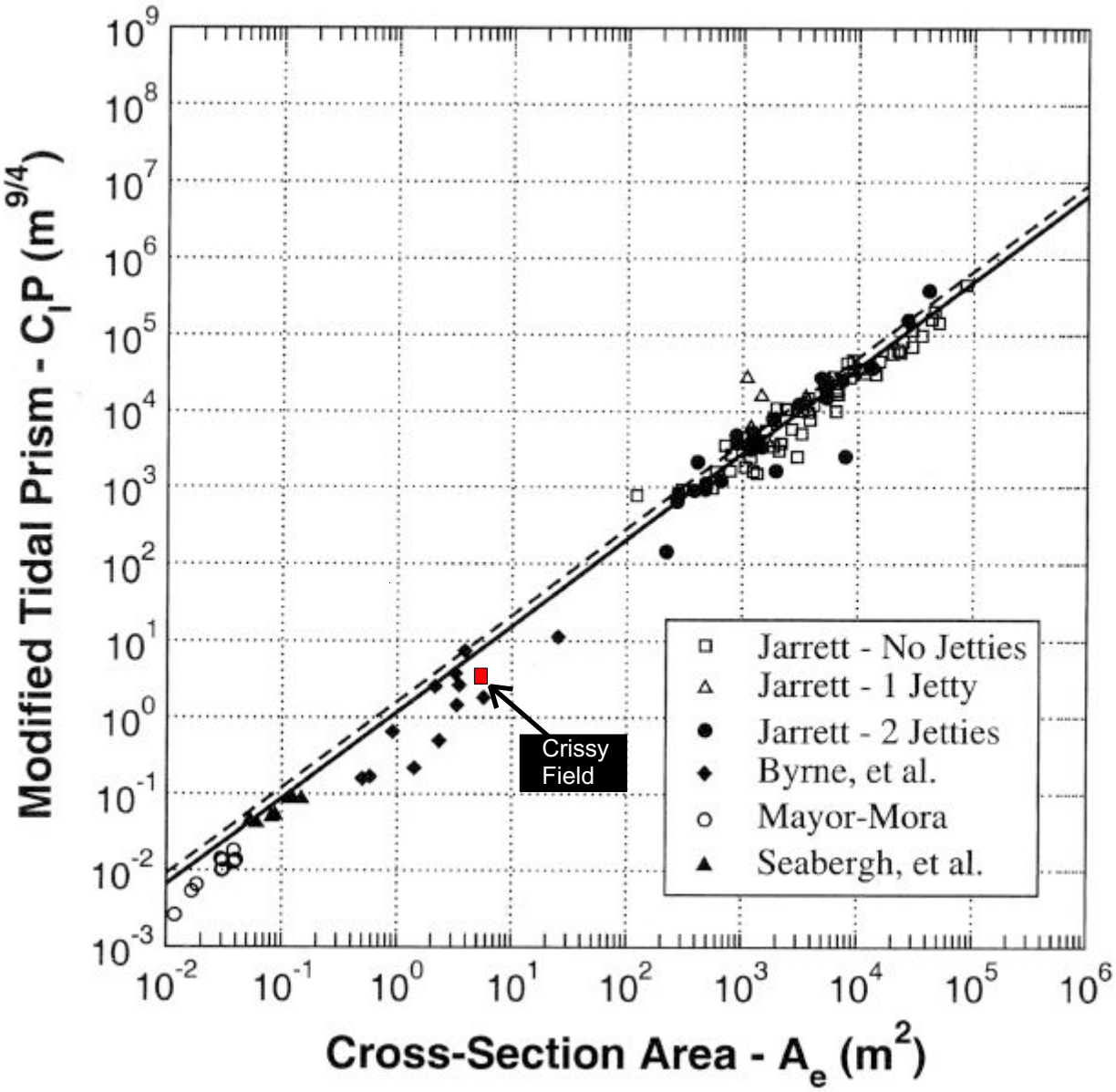


figure 6-3

Crissy Field Marsh Expansion Study

Hughes Tidal Prism Relationship and Crissy Field

PWA#: 1623

PWA

1623-00_CrissyField_Expansion_Study\Task10_Reporting\Figs\Sec6\HghsTidalPrsmRltnshp.cdr

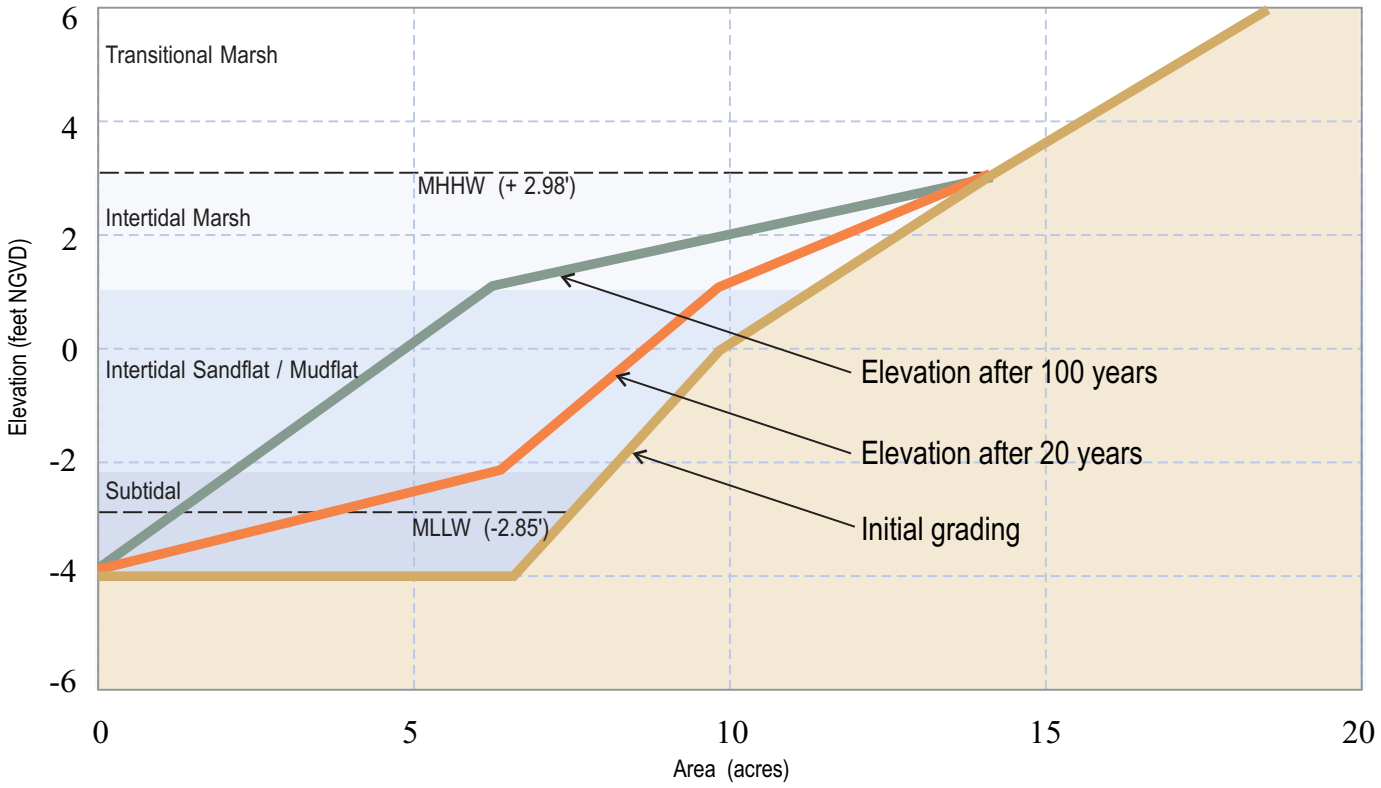


figure 6-4

Crissy Field Expansion Study

Expected Siltation at Crissy Field for Existing Wetland Site

Proj. # 1623.10 Section 6 FutureSiltation.cdr

PWA

7. A CULVERT INLET

7.1 CONCRETE ENTRANCE CHANNEL

Replacing the tidal inlet with a concrete channel (open-top culvert) would significantly reduce the risk of closure, for both the existing and expanded wetlands. This alternative would lead to much more consistent tidal flushing with less need for maintenance. However, natural tidal inlet functions and littoral transport would be lost. Longshore sand supply to the east could be reduced causing erosion to East Beach. The paragraphs below summarize modeling results used to size the culvert, and a qualitative description of the expected effects to beach processes is presented.

7.2 CHANNEL GEOMETRY AND LOCATION

Since the conveyance of the proposed concrete channel may limit the tide range inside the lagoon, PWA carried out a series of numerical simulations to determine the minimum width required to achieve full tidal action for each wetland size. Channel widths below these minimum values may restrict flow and mute the tide range. The height of the channel is determined by the tide range and invert elevation. It was assumed that the concrete entrance channel would be approximately 800 ft, extending from the interior of the wetland to approximately the –5 ft NGVD contour in the bay.

A culvert location immediately east of the existing groyne was assumed to be most practical location due to the proximity to the existing inlet and the fact that this location would minimize the groyne effect of the culvert. Culvert locations in other locations, such as at the west end of the marsh, were not considered since these alternatives would lead to more wave exposure at the mouth of the inlet and increase the potential for closure. Channel length and invert elevations assumed in the analysis are listed in Table 7-1.

Table 7-1 Channel Length, Elevations, and Roughness

Channel length	800 ft
Invert elevation at lagoon	- 4.0 ft NGVD
Invert elevation at bay	- 5.0 ft NGVD
Roughness (Manning's "n")	0.03

Observed bay tides from the Presidio tide gage and stream flow from Tennessee Hallow[3] were collected during a period of significant rainfall and high bay tides (11/15/2001 to 12/15/2001) to simulate high-flow conditions, when the discharge through the culvert is near its maximum expected value. A transient one-dimensional hydrodynamic model was applied to simulate discharge through the concrete channel and water levels in the lagoon. Channel width was varied until tidal muting was negligible and flow was

[3] 1-hour streamflow data from SD-1 measured by Kamman Hydrology & Engineering, Inc. and provided by NPS.

subcritical. Results are summarized in Table 7-2 and include the peak current velocities simulated over the spring-neap period**.**

Table 7-2. Minimum Channel Widths for Various Wetland Sizes

Wetland Size (acres at MHHW)	Tidal Prism (ac-ft)	Minimum Channel Width Required for Full Tide Range (ft)	Average Spring Peak Velocity (ft/sec)
14	47	15	2.9
18	59	15	3.4
21	71	20	3.3
25	83	22	3.4
28	94	25	2.6
32	106	35	2.9

Although channel widths less than those reported above did not mute the tide range, peak current velocities increased to supercritical values and indicate an abrupt change in hydraulic conditions as the flow transitions into subcritical levels. Since these conditions could pose a danger given the high amount of public use the facility receives, the channel width was widened until subcritical flow was present throughout the spring-neap tide cycle.

7.3 IMPACTS TO BEACH PROCESSES

A culvert will result in a different inlet and downdrift beach morphology, in response to the changed efficiency in sand trapping and bypassing as well as the associated current and wave patterns. Construction of the concrete entrance channel described above would interrupt longshore sand transport and affect the adjacent shoreline, depending on the culvert geometry and flow velocities. Since the littoral transport at Crissy Field is almost unidirectional, any culvert that extended through the surf zone would result in accretion along the updrift side (to the west) and erosion in the downdrift direction (to the east). Also, the higher velocities in a culvert would tend to discharge the sand farther offshore. Along beaches with mild slopes, natural by-passing would re-establish a continuous stream of littoral transport after some time. However, the steep nearshore slope of the bay would likely mean that the wave-induced transport would be displaced into deeper offshore waters and not remobilized. The deposited sand could accumulate and form an offshore bar that would re-connect longshore sand supply to the east, but this could take many years.

A concrete entrance would also halt the current cycle of inlet migration and spit breaching, a secondary mechanism for natural sediment by-passing that has been described in PWA 2001b. Under existing conditions, the nearly unidirectional longshore sand transport from west to east forces the mouth of the inlet to migrate eastward, and the channel elongates as it becomes nearly parallel to the shore. Wind-driven transport along the beach reinforces the wave-driven longshore transport, especially during closure. Naturally re-opening sometimes leads to a more northerly and direct channel connection to the

bay, resulting in a large quantity of sand transferred from the updrift to downdrift inlet shoreline. The degree to which a culvert affects these sand transport patterns depends on the culvert geometry and location.

Maintenance of a culverted entrance could potentially be significant. A long culvert within the elevation range of the wave-affected shore face (down to about –4 ft NGVD) would act similar to a groyne and tend to reduce sand supply to the east. This could result in the need no nourish East Beach by direct sand placement, resulting in a significant recurring expense. Also, long submerged culverts (siphons) may require cleaning of barnacles and other marine organisms from the culvert walls that would otherwise reduce the hydraulic conveyance of the structure.

7.4 BENEFITS OF OPTIMIZING CHANNEL GEOMETRY

Results presented in Table 7-2 indicate that an approximately 800-ft long concrete channel can be constructed for each of the wetland sizes, with minimum width increasing with wetland size and varying between 15 to 35 feet. The impacts to adjacent shoreline could be significant, to the extent that the natural longshore sand transport is disrupted. However, these impacts could be lessened if the length of the constructed channel was limited. One possibility is to shorten the section of the concrete channel so that tidal currents are maintained at a sufficiently high velocity to maintain an opening across the ebb bar. This would preserve the natural by-passing that presently occurs at lower tide stages, when the ebb bar serves as a conduit for the longshore transport.

7.5 CULVERTS CONSIDERED BUT NOT EVALUATED

The functions of a closed-top culvert, and its impacts on East Beach, could be significantly different depending on the geometry and location of the structure. Although we did not examine this case, some general comments on the merits and drawbacks can be made.

Closed-top culverts could be designed to maintain continuous tidal action to the lagoon and minimize impacts to East Beach, but this would be at the expense of natural tidal inlet processes and wetland functions. Siphons that extended from inside the lagoon to beyond the littoral zone (probably tens of meters offshore) would allow for exchange of water without diverting sand from the littoral stream. Since sand would by-pass Crissy Field, impacts to East Beach would be minimal. However, natural inlet processes would be disrupted. For example, morphological features such as the flood shoal could not be maintained since sand transport would be eliminated. Aquatic wildlife uses would also be significantly affected, since fish passage through the closed-top culvert is unlikely.

8. IMPACTS TO EAST BEACH

Based on past monitoring data and our conceptual model of sediment transport processes at the inlet, we expect impacts to East Beach associated with expanding the lagoon to be qualitatively similar to those observed following tidal restoration in November 1999. In general, the ebb and flood shoals represent sediment sinks that disrupted sand delivery to East Beach as they evolved. Expansion of the existing lagoon will cause these tidal shoals to enlarge, and, without other action such as pre-filling the shoals, East Beach will adjust accordingly. Although the rates of erosion would diminish as the tidal shoals reach new equilibrium conditions, the resulting changes in wave action and tidal currents near the inlet would drive East Beach to a new state of equilibrium as well. Therefore, although the beach would recover some of its short-term losses and fluctuations in response to the seasonality of waves would continue, we expect long-term changes in the beach profile and shoreline to persist. The paragraphs below describe how East Beach would be affected by expanding the existing wetland and provide estimates of the amount and rates of the impacts.

8.1 EVOLUTION OF THE EBB AND FLOOD SHOALS

It is important to understand the evolution of the tidal shoals in response to increased wetland sizes since these morphologic features store sand that would otherwise continue downdrift and maintain East Beach. Additionally, the ebb shoal serves as a conduit for natural sand bypassing around the inlet. Although the geometry of the basin will affect the size of the tidal shoals, their morphology also vary in response to changes in the prevailing wave climate and other environmental factors. For example, sand transport to the flood shoal increased markedly during large wave events that occurred during medium to high tides (PWA, 2001b). The effective tidal prism, inlet geometry, sediment supply, slope of the nearshore, and the concrete groyne west of the inlet also affect development of the tidal shoals.

Monitoring activity at Crissy Field has included periodic surveys of the tidal shoals, and the cumulative change in sand volume in both the ebb and flood shoals has been plotted in Figure 4-3. These data show that sand accumulated in the flood- and ebb-tidal shoals at approximately 400 and 1,500 CY/month, respectively, before reaching equilibrium. The rate is affected by the strength of the sediment sink, which increases with wetland size and decreases with evolution toward equilibrium, and the rate of littoral sand transport.

Walton and Adam (1976) developed the following empirical relationships between tidal prism and ebb-shoal volume by studying tidal inlets along the East Coast, mostly with mild wave exposure:

$$V_{ebb} = \forall P^{1.23}$$

where, V_{ebb} is the volume of the ebb bar in CY, P is the tidal prism in ft^3, and $\forall$ is an empirically-derived coefficient that is a function of wave exposure. Walton and Adams suggest the values listed in Table 8-1 for $\forall$ based on their study of East Coast inlets.

Table 8-1. Values of Empirical Coefficient

Wave Exposure	$\forall$
High	8.7×10^{-5}
Moderate	10.5×10^{-5}
Low	13.8×10^{-5}

Source: Walton and Adams (1976)

Results from this empirical relationship and monitoring of Crissy Field are plotted in Figure 8-1. The measured ebb volume is larger than that predicted by the empirical relationship, presumably because Crissy Field is an in-bay lagoon with lower wave exposure than the inlets studied by Walton and Adams.

Due to the discrepancy between the predicted and measured ebb shoal volumes, we derived a site-specific value of the empirical coefficient ($\forall_{CRISSY}$) so that estimates of ebb shoal volume could be made for expanded wetland sizes. Using the measured value of approximately 45,000 CY of sand and an effective tidal prism of 17 ac-ft, we found a value of:

$$\alpha_{CRISSY} = \frac{V_{ebb}}{P^{1.23}} = \frac{45{,}000\,\text{CY}}{17\text{ac-ft} \times 43{,}560\,\text{ft}^3/\text{ac-ft}} = 27.1 \times 10^{-4}$$

Using the above estimate of $\forall_{CRISSY}$ and the functional relationship derived by Walton and Adam, estimates of the ebb shoal volumes listed in Table 8-2 were established. The time required for the newly formed ebb shoal to reach equilibrium is estimated by assuming the measured rate of accumulation (1,500 CY/month) increases proportionally with tidal prism. Based on this analysis, a wetland expanded to about 32 acres at MHHW would produce an ebb bar about three times the current volume, and require approximately 2½ years to reach equilibrium.

The maximum rate of sand deposition is limited by the gross longshore and onshore transport rate, driven primarily by waves, and an increase in these gross rates induced by the inlet itself. Given that there is a limited sand volume in East Beach to satisfy increased gross transport and that longshore transport rate is nearly unidirectional at Crissy Field (from west to east), the net longshore sand transport rate from the west can be used as a reasonable surrogate for the gross rate. A potential long-term net transport rate at Crissy Field of about 25,000 to 33,000 CY per year has been reported previously (PWA 2001a, 2001b). Using 29,000 CY per year as an average value of the net transport rate, the maximum deposition rate indicates a longer time to attain the equilibrium geometry, which is indicated in the column "Supply Limited Time to Equilibrium" in Table 8-2. For example, the limited sediment transport rate extends the time required for the ebb shoal of a 32-acre marsh to reach equilibrium to about 5 years.

Table 8-2. Estimated Ebb Shoal Volume for Expanded Wetlands

Wetland Size at MHHW (acres)	Tidal Prism (ac-ft)	Ebb Shoal			
		Volume (CY)	% Change in Volume	Time to Equilibrium (months)	Supply Limited Time to Equilibrium (months)
14	17	45,000	n.a.	n.a.	n.a.
17 ½	24	68,800	55 %	11	10
21	31	94,200	110 %	18	20
42 ½	39	125,000	175 %	23	33
28	47	157,000	250 %	27	46
31 ½	56	195,000	335 %	30	62

n.a. = not applicable to existing wetland

8.2 CHANGES TO EAST BEACH

East Beach includes the entire shoreline from the concrete groyne (sometimes referred to as a jetty or West Jetty) on the west to the beginning of the rock revetment to the east. Significant morphological changes occurred to this section of the beach following restoration of tidal action in November 1999, and we expect impacts associated with wetland expansion to be qualitatively similar but different in magnitude. Previous reports (PWA, 2001a; 2001b) have documented changes in the profile and shoreline of East Beach from November 1999 through May 2001, a period in which the beach was adjusting to the newly constructed lagoon at Crissy Field. These adjustments included erosion of the beach east of the inlet, accompanied by rotation of the shoreline and changes to the beach profile. The rate of erosion slowed, and in some places recovered, as the system evolved to a new equilibrium. Expansion of the existing lagoon would result in further adjustments, as the system tends to a different equilibrium state in response to changes in the wave climate, tidal power, and inlet morphology.

Transects collected across East Beach show that its profile changed from a fairly uniform slope before restoration to a compound profile with a steeper upper portion, a flatter mid portion, and a steeper lower portion. Impacts were more pronounced closer to the inlet, as demonstrated by beach profiles 12-E and 13-E (Figure 8-2). (Note that the accretion shown in the 02/27/2002 and 10/08/2002 surveys was likely a result of inlet closure.) The formation of this compound beach profile suggests that sediment delivery to East Beach is reduced in the upper tide range, but natural bypassing occurs at lower water levels. At the upper tide range, flood currents divert sand into the lagoon that forms the flood shoal or accumulates in the entrance channel. Enhanced longshore transport past the inlet and inlet bypassing occurs at lower stages of the tide due to the large amount of tidal muting and formation of the ebb shoal, leading to accretion at lower elevations (PWA, 2001b). Figure 8-3 shows, at a conceptual level, these transport patterns and the expected change in the beach profile near the inlet. Note that some of the sediment transported out of the tidal inlet by ebb currents in the channel are “lost” to deep portions of the bay, however most of the sand remains in the littoral stream.

The “hinge point” in the beach profiles between the wider low tide beach and the narrower high tide beach is related to wetland size. More specifically, the elevation of this hinge point is near the inlet channel thalweg where it crosses the beach (called the beach sill). As the wetland area and tidal prism increase, the thalweg lowers and the profile hinge point lowers.

In addition to changes in the beach profile, adjustments to the shoreline of East Beach occurred in response to the diminished sediment supply downdrift of the inlet. Erosion near the inlet caused the shoreline to rotate counterclockwise, before accretion recovered some of the loss of beach width. A similar pattern of shoreline adjustments is expected following expansion of the existing lagoon, as shown conceptually in Figure 8-4.

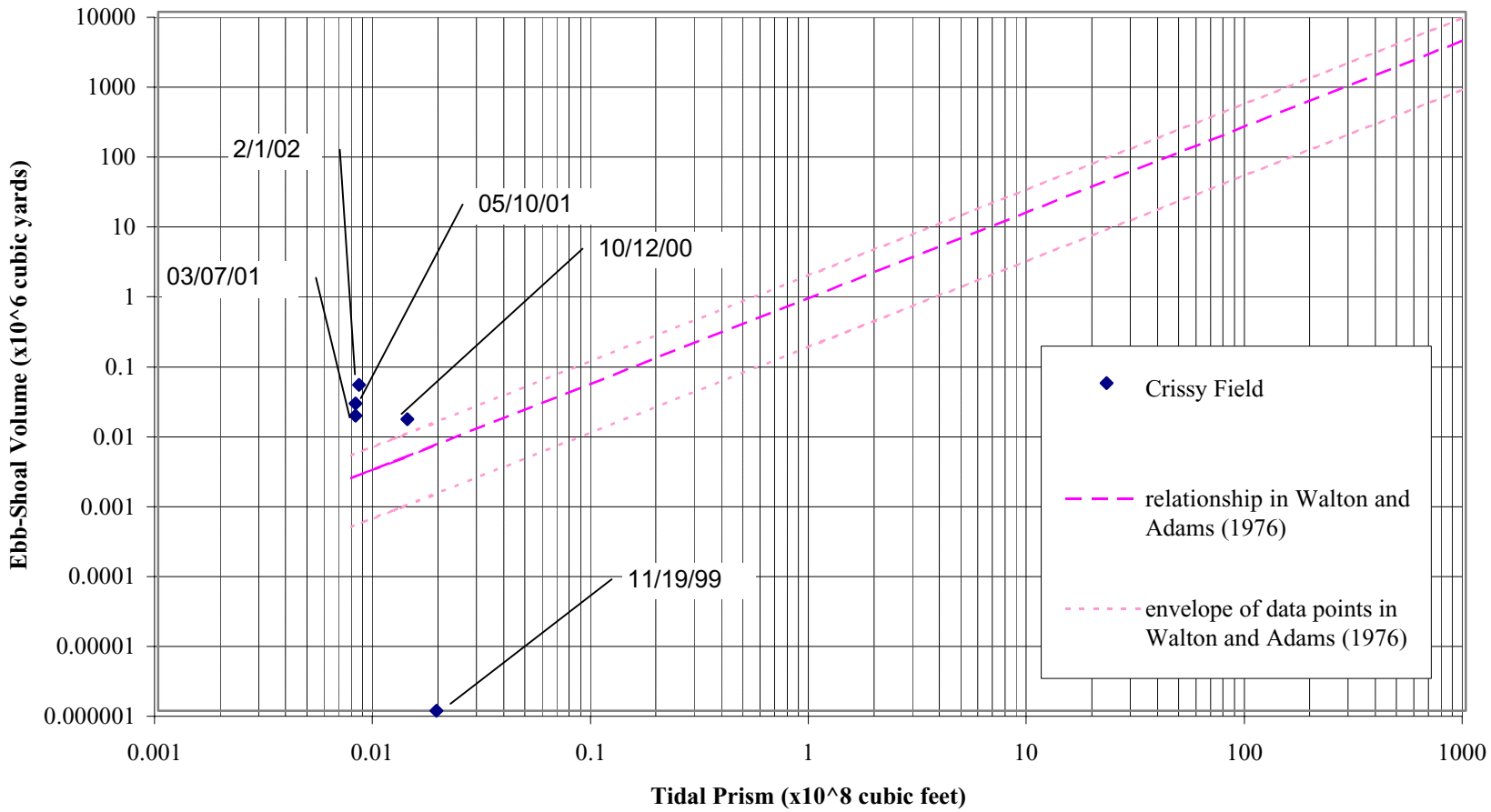
8.3 A NEW EQUILIBRIUM

Expansion of the lagoon basin is expected to induce short-term changes to the morphology of the tidal shoals and East Beach. Many of the adjustments to East Beach will be temporary, with the rates of erosion diminishing as the ebb and flood shoals evolve to new equilibrium conditions. However, these changes to the inlet morphology will affect the wave and tidal conditions, and hence the sediment transport patterns, leading to a new equilibrium state.

Reliable empirical estimates of flood shoal volumes do not exist. However, assuming that the increase in sand volume over the flood shoal is proportional to increases in the ebb shoal volumes, we can make rough estimates of the magnitude of the impacts to East Beach. Table 8-1 lists the predicted ebb shoal volumes, and gives a relative comparison among the expanded wetland sizes under consideration. For example, expanding the wetland to 21 acres at MHHW would results in a 110% increase (roughly double) in sand volume in the ebb shoal. Therefore, we can expect the expanded lagoon to accumulate roughly the same amount of sand as after the initial marsh construction, suggesting that short term impacts will be similar to those observed following tidal restoration in November 1999.

The flood shoal will grow laterally by spreading into the lagoon, but is not expected to increase in height. The length scale of the inlet channel will also increase with the tidal prism. Since the ebb shoal is “pinched” against the shore by the steep slope of the nearshore (bayshore) profile and wave action, we anticipate that most of this lengthening will be manifested in a further laterally spreading of the flood shoal into the lagoon.

Some sand has deposited in relatively deep water at the toe of the ebb shoal. This sand is believed to be delivered to the offshore during strong ebb flows that carry the sand through the narrow surf zone, and down slope. Also, the north face of the ebb shoal is steep and may slough. Monitoring data indicate a thin sand deposition has accumulated since wetland construction. We expect that this deposition rate of this offshore sand “loss” will increase with the peak ebb flow associated with a larger wetland.



Source: PWA surveys, Walton and Adams (1976)
Notes: Diurnal tidal prism calculated for Crissy Field.
Ebb-shoal volume approximated with Control Volume 2 designated by PWA.
Relationship for minimally exposed inlets used.

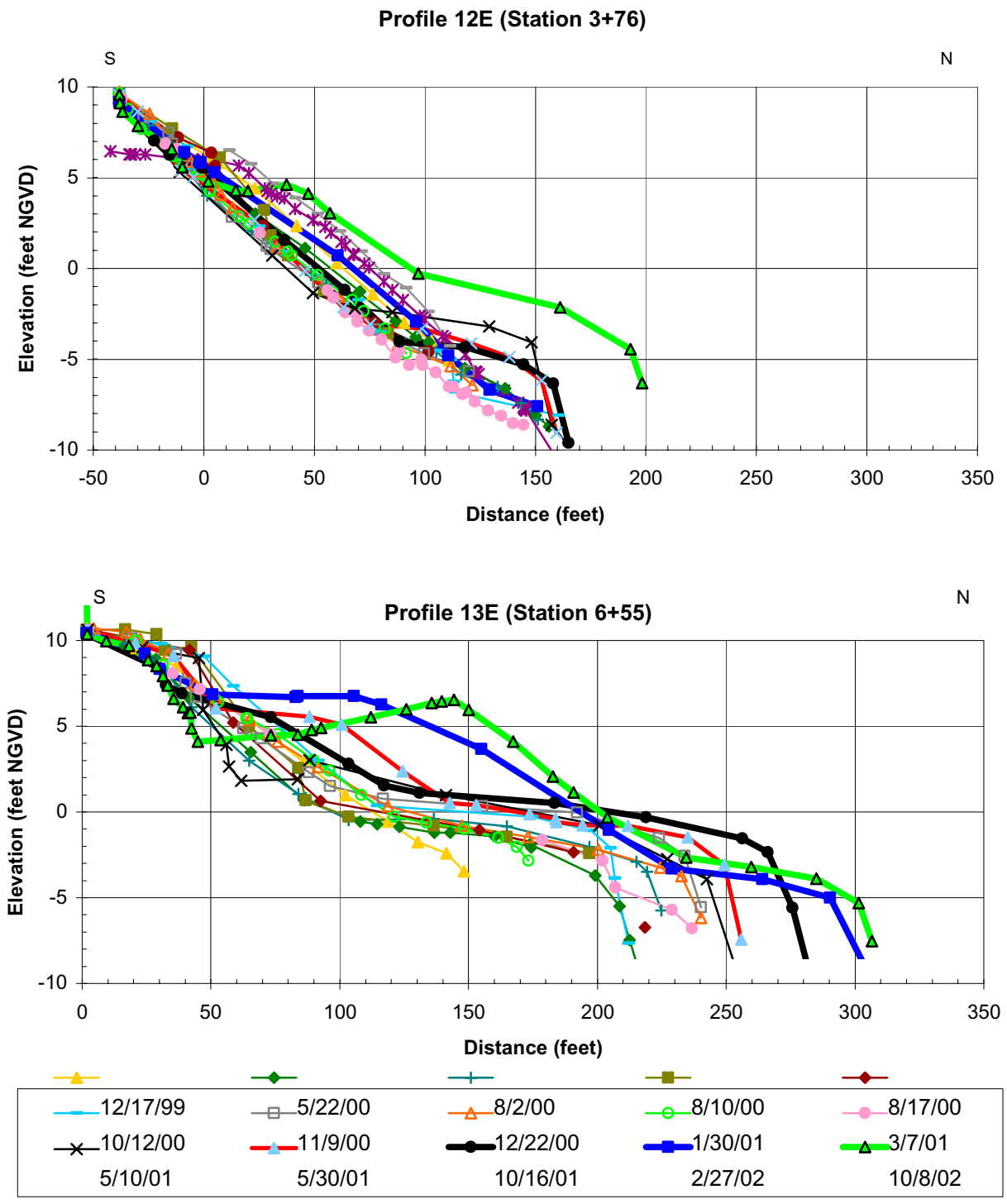
figure 8-1

Crissy Field Marsh Expansion Study

Tidal Prism versus Ebb-Shoal Volume

PWA#: 1623

PWA



Notes: Inlet was closed during 10/8/2002 survey, and 2/27/2002 survey followed mechincal breach on 1/16/2002.

Source: PWA surveys

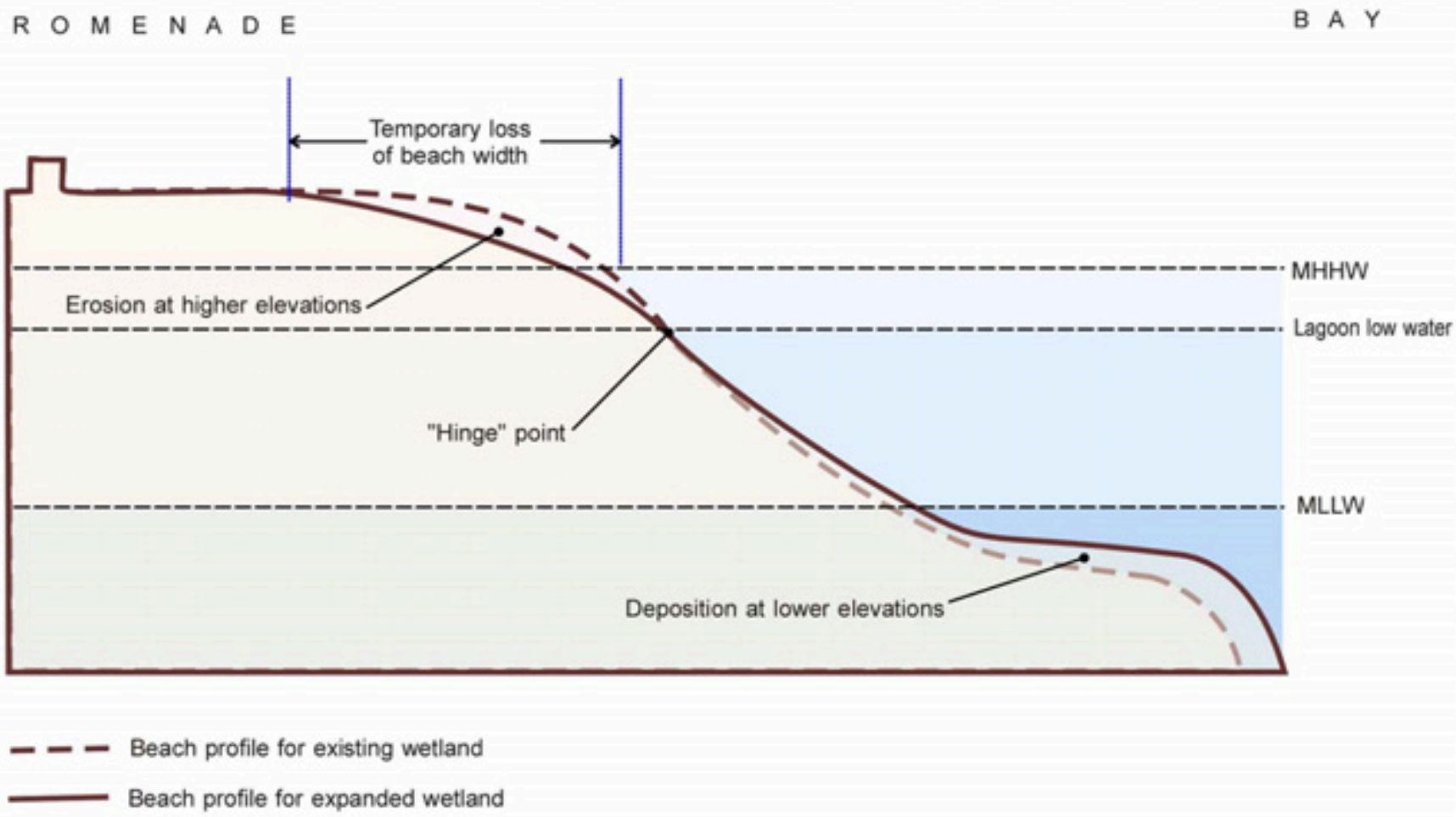
figure 8-2

Crissy Field Marsh Expansion Study

Beach Profiles 12E and 13E

PWA#: 1623

PWA



NOT TO SCALE

figure 8-3

Crissy Field Marsh Expansion Study

Conceptual Adjustments to Beach Profile

Proj. # 1623.00 Beach Profile2.cdr

PWA

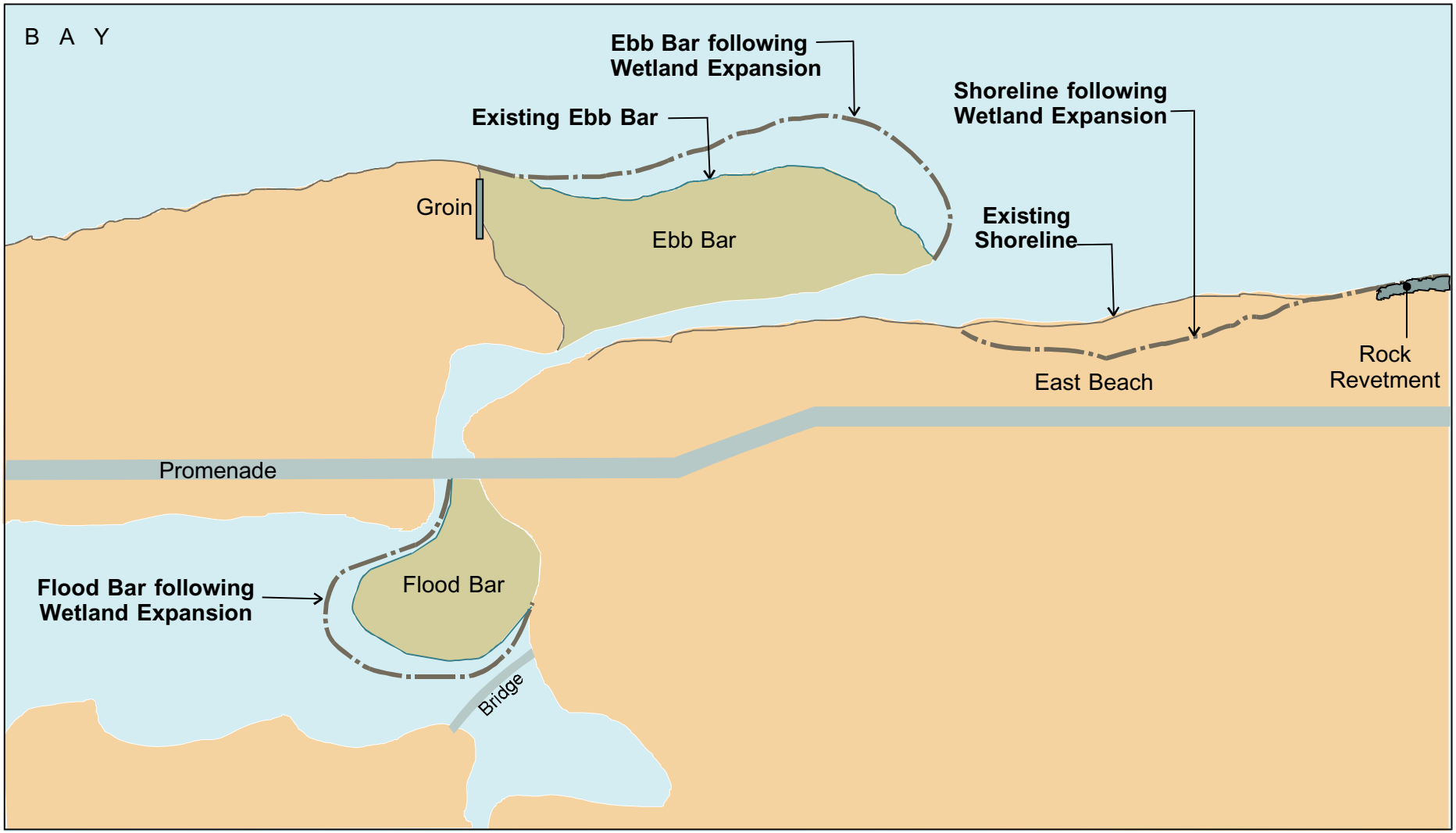


figure 8-4

Crissy Field Marsh Expansion Study

Shoreline Adjustments along East Beach

Proj. # 1623.00 SHORELINE.cdr

PWA

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This report was prepared by the following PWA staff:

Don Danmeier, Project Manager
Robert Battalio, Project Director
Philip Williams, Technical Advisor

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Technical oversight was provided by an provided by an independent Technical Review Group, consisting of the following individuals:

Dr. Roberto Anima, United States Geological Survey
Dr. Rebecca Beavers, National Park Service
Dr. Andree Breaux, Regional Water Quality Control Board
Kevin Knuuti, United States Army Corps of Engineers
Michelle Levenson, San Francisco Bay Conservation and Development Commission
Michael Munroe, United States Environmental Protection Agency
Professor Robert Wiegel, University of California at Berkeley