Bolinas Lagoon Ecosystem Restoration Feasibility Project

Final Public Reports

IV Conceptual Littoral Sediment Budget

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MEMORANDUM

DATE: July 11, 2005
TO: Al Paniccia
COMPANY: USACE
FROM: Don Danmeier and Philip Williams
COPY TO: Bill Carmen
RE: Conceptual Littoral Sediment Budget at Bolinas Inlet
PWA Ref. #: 1686.03

INTRODUCTION

In cooperation with the U.S. Army Corps of Engineers (USACE), the Marin County Open Space District (MCOSD) is developing management options for Bolinas Lagoon, a 1,100-acre lagoon in west Marin located 15 miles north of San Francisco (Figure 1) and is currently re-formulating the Bolinas Lagoon Ecosystem Restoration Project described in the June 2002 Draft Feasibility Report and Environmental Impact Statement / Environmental Impact Report. As part the formulation of management options, MCOSD has contracted Philip Williams & Associates (PWA) to develop a projection of future lagoon evolution. Public meetings were held early in the planning process, during which the following questions were raised regarding the effects of coastal structures in the vicinity of the tidal inlet:

- Have the Bolinas groin and armoring at Seadrift affected net sedimentation in the lagoon?
- How have these structures changed the beaches adjacent to the inlet and the movement of sand?

Prompted by these questions, PWA began a review of sediment and beach dynamics at the Bolinas Lagoon inlet, including the development of a conceptual budget of littoral sediment. This memorandum summarizes our findings.

PWA analyzed historic aerial photographs provided by the USACE, performed field reconnaissance, and reviewed previous reports to identify the effects of existing infrastructure on coastal processes at the project site. A description of sediment dynamics, including a discussion of sources, sinks and pathways, has been included in a conceptual budget of littoral sediment. The USACE has funded this study.

FINDINGS AND CONCLUSIONS

The following findings and conclusions are based on literature review, analysis of historical photographs and site reconnaissance by PWA staff.

- Bolinas Lagoon is located within a littoral cell that extends from Duxbury Reef in the north to Rocky Point in the south. Mineralogical studies show that bottom sediments in Bolinas Bay are similar to those along San Francisco Bar, indicating that the material is either transported northward by deep coastal currents or was deposited by geologic process when sea level was much lower and sand moved along the continental shelf under the influence of waves. A portion of the bottom sediments is derived locally by erosion along the Bolinas bluffs, discharge from Webb Creek, and export from Bolinas Lagoon during ebb tides.

- Seasonal changes in wave climate and the occurrence of strong El Nino winter storms are the primary causes of fluctuations in beach width. Seasonal changes of up to 130 ft at Stinson Beach are typical, with beach widths at a maximum during summer and smaller in winter. GIS analysis of historic photographs shows that strong El Nino events also contribute to the variability in beach width.

- Stinson Beach has recovered relatively quickly following past winter storms, indicating that most of the sand eroded from the beach is stored offshore in subtidal bars and later moved shoreward when the wave climate moderates. Permanent losses of sand to deep portions of Bolinas Bay during winter storms are probably small.

- A properly functioning Bolinas groin partially traps longshore drift directed toward the inlet and is effective at increasing the size of Brighton Beach. However, the effects of the groin on coastal processes are limited due to its relatively low elevation and short length. Wave breaking around the tip of the groin and inundation at high tide demonstrate that sand bypasses the structure once the beach builds-up to its equilibrium size.

- Waves reflected from riprap along Seadrift Beach focus wave power along the nearshore and have the potential to lower the equilibrium beach profile. A lower beach elevation increases wave attack on the structure, especially at its toe where PWA staff observed dislodged rocks during a field visit in January 2004. Although a mechanism for reducing longshore transport has been identified (i.e., lowering of the beach by wave focusing), data reviewed by PWA do not reveal any change in beach morphology due to installation of the riprap, and its effects on existing rates of longshore transport are expected to be minor.

- Construction of bulkheads along the lagoon side of Seadrift has created a less dynamic channel system. Evidence of strong erosion potential is evident along the sandy banks of the channel immediately adjacent to the bulkheads. Although installation of bulkheads along Seadrift had reduced the potential for the channel to erode through Stinson Spit and ‘break-out’ at a new inlet location, its effects on the long-term delivery of beach sands into the lagoon are limited since any new tidal inlet would quickly migrate westward to its present location in response to the longshore transport along the spit, which is directed from Stinson Beach toward the Bolinas Inlet.

A CONCEPTUAL LITTORAL SEDIMENT BUDGET AT BOLINAS INLET

The form of Bolinas Lagoon and its mix of habitats are controlled by the amount of sediment stored in the lagoon relative to the rate of sea level rise and tectonic subsidence. The net change in sediment storage within the lagoon is distributed across different geomorphic 'units' (e.g., tidal channels, fluvial deltas, salt marsh and mudflats) by various earth-shaping processes. Therefore, an accounting of the inputs, outputs, and storage – a 'sediment budget' – of beach sand swept through the tidal inlet will assist in the prediction of future lagoon shape and size, as well as in identifying the dominant sources of sedimentation. In general, the sediment budget for the inlet can be expressed as:

$$\Delta \text{ Sediment Storage} = \text{Sediment Input} - \text{Sediment Output}$$

Sediment transported through the tidal inlet is complicated by dynamic interactions of tidal and wave processes and the fact that sediment along the coastline originates from several sources. In order to better explain observed morphologic changes in the lagoon and adjacent beaches, we have identified pathways of sediment movement in the vicinity of the tidal inlet as shown in Figure 2. Each term in the conceptual budget is described below. The expected magnitude of each term is provided qualitatively; quantitative information is provided where possible.

1. <u>Bluff erosion along Bolinas</u>. Wave attack along the bluffs west of Bolinas delivers sediment to the littoral zone that is subsequently transported toward the inlet by wave and tidal currents (Figure 3). These bluffs, which are primarily composed of erodible Monterey Shale, are receding at a rate of about 1.5 ft/yr, resulting in approximately 1 million cubic feet (mcf) per yr(or about 37,000 cubic yards per year (CY/yr) of sediment introduced to the littoral zone (Ritter, 1973). Wave action and currents sort the sediment deposited at the base of the bluffs, leaving coarse-grain sands along the beaches and transporting a portion of the eroded material toward Bolinas Lagoon and a portion into deeper water in Bolinas Bay.

2. <u>Longshore transport along Stinson Spit</u>. Refraction of deep offshore waves typically results in sand transport along Stinson Spit directed toward the northwest, as demonstrated by the orientation of Stinson Spit and computations by Battelle (1984). Based on standard energy flux methods (USACE 1984), Battelle (1984) estimated a net longshore sediment transport *potential* of about 8.1 mcf/yr (300,000 CY/yr). Although the actual amount of sand transport is expected to be much less, the relatively large potential for sand transport along the spit demonstrates that coastal processes delivers substantial amounts of littoral sediments to the lagoon mouth.

3. Flood-tide transport through inlet. Beach sand deposited at the mouth of the inlet by longshore currents is swept into the lagoon during flood tides if current velocities are sufficiently high. Turbulent wave breaking on the shallow bar immediately offshore mobilizes sand into the water column, where it is more easily carried as suspended load into the lagoon. Ritter (1973) estimated that the annual transport of sediment through the tidal inlet during flood tides is approximately 3.5 mcf/yr (129,000 CY/yr). However, his estimate probably understates the actual amount of beach sands swept into the lagoon since his sediment rating curve was based on data collected during three calm summer days when littoral transport was significantly less than during intense winter storms.

   Sands swept into the lagoon deposit to form flood-tide shoals as tidal current velocities slacken. A portion of the material deposited on these intertidal flats is subsequently re-mobilized and exported from the lagoon by ebb currents (see below) or transported to other portions of the lagoon. Eventually a dynamic equilibrium is established based on the relative influence of tidal prism and sediment availability.

4. Ebb-tide transport through inlet. A portion of the sand deposited in channels and flood-tide shoals during flood tides, as well as stream-borne sediments, is exported out of the lagoon and into Bolinas Bay when tidal currents ebb. Using a rating curve established during ebb flows, Ritter (1973) estimated that the annual transport of sediment through the tidal inlet during ebb tides to be approximately 3.8 mcf/yr (139,000 CY/yr). This estimate is similar to his estimate of sediment transport during flood tides. However, the presence of flood tide shoals and the sandy texture of bottom sediments within the lagoon indicate that net transport over the long-term is *into* the lagoon. We suspect that Ritter's conclusion of ebb-dominated discharge is incorrect. This is not surprising given that he was estimating the very small difference between two large numbers (net transport is only 4% of the gross transport).

   Sand transported through inlet during ebb tides deposit on a subtidal shoal immediately offshore of the inlet mouth as tidal currents fan and velocities slacken. Wave action in Bolinas Bay limits the height of this ebb-tide shoal. The volume of sand stored on the ebb shoal changes in response to seasonal variation in wave climate (Johnson 1973).

Although transport pathways are complex, the high rates of sediment exchange through the inlet and transport potential along the beaches indicate that coastal processes are probably a significant factor influencing net sedimentation in Bolinas Lagoon.

Table 1. Order-of-Magnitude of Sediment Budget Terms

Sediment Budget Term	**Order of Magnitude (ft^3/yr)**	**Comments**
Erosion of Bolinas bluffs	$\sim 10^6$	Based on 1.5 ft of bluff retreat (Ritter 1973). Fine silt is transported toward the inlet or lost to deepwater. Coarse to medium sands stay at Brighton Beach.
Longshore transport potential along Seadrift	$\sim 10^7$	Net longshore transport *potential* is directed toward inlet (Battelle 1984). Infrequent waves that approach from the south-southwest account for most of the sand transport.
Flood-tide transport through inlet	$\sim 10^7$	Influenced by lagoon tidal prism, availability of beach sands in littoral zone, and wave breaking on ebb bar that suspends sand into water column.
Ebb-tide transport through inlet	$\sim 10^7$	Influenced by lagoon tidal prism. Some re-suspension of sand due to internal wind-waves, although this is much less that induced by wave breaking on ebb bar.
Net transport through inlet (change in sediment storage) + into lagoon - out of lagoon	$\sim +10^5$	Net transport affects sediment storage in lagoon, and is influenced by the relative balance of tidal prism and sediment availability. High gross-to-net ration demonstrates that sedimentation may be rapid if equilibrium is disturbed (e.g., after large earthquake). Transport into the lagoon may also be accelerated during energetic coastal storms.

BEACH DYNAMICS AND PATTERNS OF SAND TRANSPORT

Wave action and tidal currents influence the movement of sand, which in turn leads to changes in beach morphology. Changes to the width, elevation, slope and orientation of the beach occur over the long- and short-term in response to the seasonality and year-to-year variation in wave climate. In general, energetic winter waves erode sand from the beach face to subtidal bars immediately offshore. This sand is then gradually transported back onto the beach when wave action is more moderate during summer and autumn. In response to these seasonal patterns, beaches at Seadrift and Bolinas usually vary in width and elevation in response to the seasonality of wave conditions (Figure 4).

In order to quantify beach dynamics, PWA staff reviewed eleven aerial photographs collected from 1942 to 2001 using GIS tools. PWA staff digitized the average high water line for each photograph by examining differences in reflectance and micro-topography such as wind-rippled sand. Beach width was then computed as the distance from the average high water line to the vegetation line for the 10 transects shown in Figure 5[1]. Beach widths measured at each transect are plotted in Figure 6, while Figure 7 shows the average, minimum and maximum beach width measured along the beach for each photograph. As demonstrated by these results, most of the variance in beach width is within the typical seasonal variability reported by others (Johnson, 1973) or occurred after strong El Nino winters. Beach recovery appears to be complete, even after intense El Nino years. Overall, these results do not reveal any long-term trend in beach width that can be attributed to armoring of the Seadrift, suggesting that most of the eroded sand is temporarily stored in offshore bars and later transported back onto the beach.

In addition to the seasonality of the wave climate, nearshore bathymetry and shoreline orientation greatly affect the wave-induced sand transport. Along most of the coastline in north-central California, the prevailing northwest waves move beach sands southward once the sediment is mobilized by turbulent wave breaking. However, in a few localized areas that are sheltered from the prevailing waves by headlands or reefs, the net transport of sand is to the north. This is the case along Stinson Beach, were erosion-resistance bedrock at Duxbury Reef shelters Bolinas Bay from the prevailing northwesterly waves. As with Limatour Beach, which is protected from northerly waves by Point Reyes, Stinson Spit is a stable geomorphic feature that has been formed by the net longshore sediment transport directed toward the north. Because of the orientation of the shoreline at Bolinas, waves that approach from the south to southwest account for most of the sand transport along the beaches of Bolinas Bay although they occur less frequently. Analysis of nearshore processes at Stinson Beach suggest that waves from these

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[1] Based on Daniels et al (1998), the average high water line was determined was located on the aerial photographs based on the following cues: (1) landward of smooth sand (high reflectance); (2) landward of dewatering line (low reflectance); (3) seaward of wind-rippled sand that represents long subaerial exposure; (4) seaward of the drift line formed by debris; and (5) seaward of the vegetation line.

directions only account for about 20% of the annual deepwater wave power but generate 90% of the net annual longshore sediment transport potential (Battelle, 1984).

Field experiments performed by the U.S. Geologic Survey (USGS) have added to the understanding of longshore sediment transport patterns at Bolinas Bay (Ritter 1973). Fluorescent dye placed on beach sands and then tracked during the summer months of 1968 indicated longshore sediment transport of sand along Brighton Beach consistently towards the inlet, while longshore transport at Stinson Beach Park reversed direction. Although the USGS dye studies did not indicate movement of sand across the tidal inlet, the presence of cobble along the Stinson side of the entrance channel suggest that some material from the Bolinas side of the lagoon is transported toward the southeast. Figure 8 presents photographs taken by PWA staff in January 2005 that show cobble-size material along the lagoon side of Stinson Spit near the inlet. This material is most likely derived from the eroding cliffs along Little Mesa and transported into the lagoon during strong flood currents. Wave action across the shallow ebb bar allows for natural by-passing of sands across the tidal inlet.

Outside of the wave-dominated zone closest to the shore, deep coastal currents move bottom sediment along the floor of Bolinas Bay and beyond. Analysis of sediment texture and mineralogy (Wilde et al, 1969) reveal similarities between the bottom sediments of Bolinas Bay and sand found at San Francisco Bar. This suggests that material is either actively transported northward by deep coastal currents, or was deposited by geologic processes when sea level was much lower and sand moved along the continental shelf under the influence of waves. Between the deepest portions of Bolinas Bay and the shore, the analysis by Wilde et al (1969) show a mixture of locally-derived material with sand from San Francisco Bar.

IMPACT OF COASTAL STRUCTURES

Various structures have been built in the project area in response to erosion that has reduced public access and/or threatened existing infrastructure. The following paragraphs describe the structures with the greatest potential to affect coastal processes. These include: the Bolinas groin; armoring along Seadrift Beach; residential development along Seadrift; and the bulkheads on northern edge Seadrift.

- The Bolinas Groin. The first groin at Bolinas was constructed in the 1880's to increase the width and stability of Brighton Beach. This timber and plank structure was effective at establishing a 200 to 300-ft wide beach, although severe winter storms periodically damaged the groin and resulted in a loss of beach width. The groin was privately maintained until the 1930's, at which time maintenance ceased and the groin began to fall into disrepair. The original timber groin was completely destroyed by the winter storms of 1942, and by the mid-1940's the sand along the beach had been removed by wave action, exposing bedrock and greatly increasing cliff erosion.

The first concrete groin was built in 1947 and consisted of a 224-ft long trapezoidal section (approximately 5 ft high and 2 ft wide at its bottom) that bore directly on bedrock. This structure was effective at maintaining beach width and elevations throughout the mild winters of the 1950's and 60's. However, successive winter storms, particularly during 1977-78 and 1982-83, damaged the groin and reduced its ability to trap sand. In 1988, a new groin consisting of a 240-ft long series of steel H piles embedded in the beach rock with precast concrete panels was installed.

The effects of the Bolinas groin on longshore transport is evident from historical observations; from the late 1880's to the present day, the presence of an intact structure has been increasing the size of Brighton Beach effectively by impounding sand moving toward the inlet. The relatively short length and low elevation of the groin limit the effects of the structure, with sand bypassing the structure once the beach builds up to its equilibrium profile (Figure 9). Assuming a beach length and width of 600 ft and 240 ft, respectively, and 7 ft of vertical accumulation, the groin traps approximately 1 mcf of sand. The localized trapping of sand probably has a limited influence on the pattern of sand transport near the inlet by deflecting the longshore drift slightly offshore, with probable negligible effects on littoral sediment inflows to the lagoon.

- <u>Armoring at Seadrift Beach.</u> In 1978 a limited length of rock revetment was placed in front of nine homes along the downdrift end of the spit (near the inlet) in response to erosion from storms during the winter of 1977-78. This revetment was extended to six more lots in 1980. The present 7,500-ft long rock revetment was built in 1983 – an extension of the armoring installed during 1978 and 1980 – after severe wave-induced erosion along Stinson Beach was caused by a series of record El Nino storms in winter of 1982-83. Battelle (1984) attributed the large amount of beach erosion during the 1982-83 winter not to the magnitude of the storms but their frequency; eleven major storms with deepwater wave heights in excess of 10 ft occurred from November 1982 through April 1983, with storms almost continuous during January and February. Wave-induced erosion during this period produced a 6- to 8-ft scarp along Stinson Beach, exposing a thin veneer of coarse gravel and an erosion-resistant clay hardpan near the high-water line that probably limited the further beach recession by partially dissipating waves energy (Battelle 1984). Rapid recovery of Stinson Beach followed the intense erosion induced by the 1982-83 storms, with almost full restoration of pre-storm conditions by January 2004.

  The original revetment was constructed using stone 2 to 3 ft in diameter (½ to 1½ tons in weight) and placed at a 2.5:1 (horizontal:vertical) slope, with a crest elevation of +17.5 ft MLLW and a toe elevation of approximately +7 ft MLLW. A 1998 visual inspection of the structure found that armor stone had become dislodged or subsided at numerous areas along its entire length, exposing bare earth or the smaller engineers rock (6 to 12 inches in diameter) at steep grades. In response to the deteriorated condition of the armor, approximately 5,000 tons of stone (about 17%

of the original amount) were placed along the revetment in 2004 to re-establish its original design configuration. Rock placed during the 2004 maintenance averaged 2.85 ft in diameter (1¼ tons).

The effects of rock revetment at Seadrift are difficult to quantify and vary due to site-specific conditions, but the response of beach processes and morphology may be described qualitatively. In general, the steep profile of the riprap, relative to the more gentle slope of a natural beach, increases wave reflection and results in lower beach elevations, especially during the winter when waves are more energetic. Lower beach elevation in turn increases the exposure to wave attack and accelerates the rate at which rocks along the toe of the riprap are dislodged. (PWA staff observed rocks dislodged from the recently repaired structure. See Figure 10.) The lower beach elevation and absence of backdunes probably extends the time required for the beach to recover to pre-storm conditions. If beach elevations lower substantially for prolonged periods of time, longshore transport of sand could diminish as fewer and fewer waves are able to 'feel' the bottom and move sand westward.

Although the process of wave focusing could possibly result in reduced longshore transport, data presented in Figures 6 and 7 suggest that this has not so far occurred at Seadrift Beach (i.e., there is no trend of beach width loss at the downcoast transects). Presumably, this is because most of the riprap is presently exposed to wave attack during winter conditions only when the beach profile is generally lower. Accelerated sea level rise and continued erosion at the toe of the structure may affect longshore transport in the future.

- <u>Bulkheads inside Bolinas Lagoon</u>. The first bulkhead constructed along the lagoon side of Stinson Spit consisted of approximately 675 linear ft of timber and asbestos sheet pile wall. Strong tidal currents along the main channel of the lagoon eroded this structure over the years, requiring reinforcement by placing vertical timber sheet lagging along the waterside of the structure. Failure of the asbestos and timber bulkhead continued, and in 1998 the structure was completely replaced by the interlocking steel sheet pile wall shown in Figure 11. During the replacement, the toe of the bulkhead was extended from –6 ft MLLW to an elevation of approximately –21 to –27 ft MLLW to prevent tidal currents along the main channel from undermining this part of the structure.

  Construction and maintenance of the bulkhead has reduced the migration of the main tidal channel in Bolinas Lagoon and created a more 'rigid' system. Shoaling along the Bolinas Channel over the past few decades has focused all of the tidal flows through the main channel, increasing its scour potential and modifying its natural equilibrium planform. In an unconstrained channel system (i.e., without the bulkhead) it is possible that the main channel could breach the spit at a new location. However, the westward net longshore transport along Seadrift Beach would re-establish the inlet at its present location where wave exposure is less due to sheltering from Duxbury Reef. Based on the relatively large and unidirectional longshore transport potential computed by Battelle (1984), we would expect that any newly created inlet would be short-lived and have little effect on the long-term sediment delivery of beach sands into the lagoon.

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FIGURES

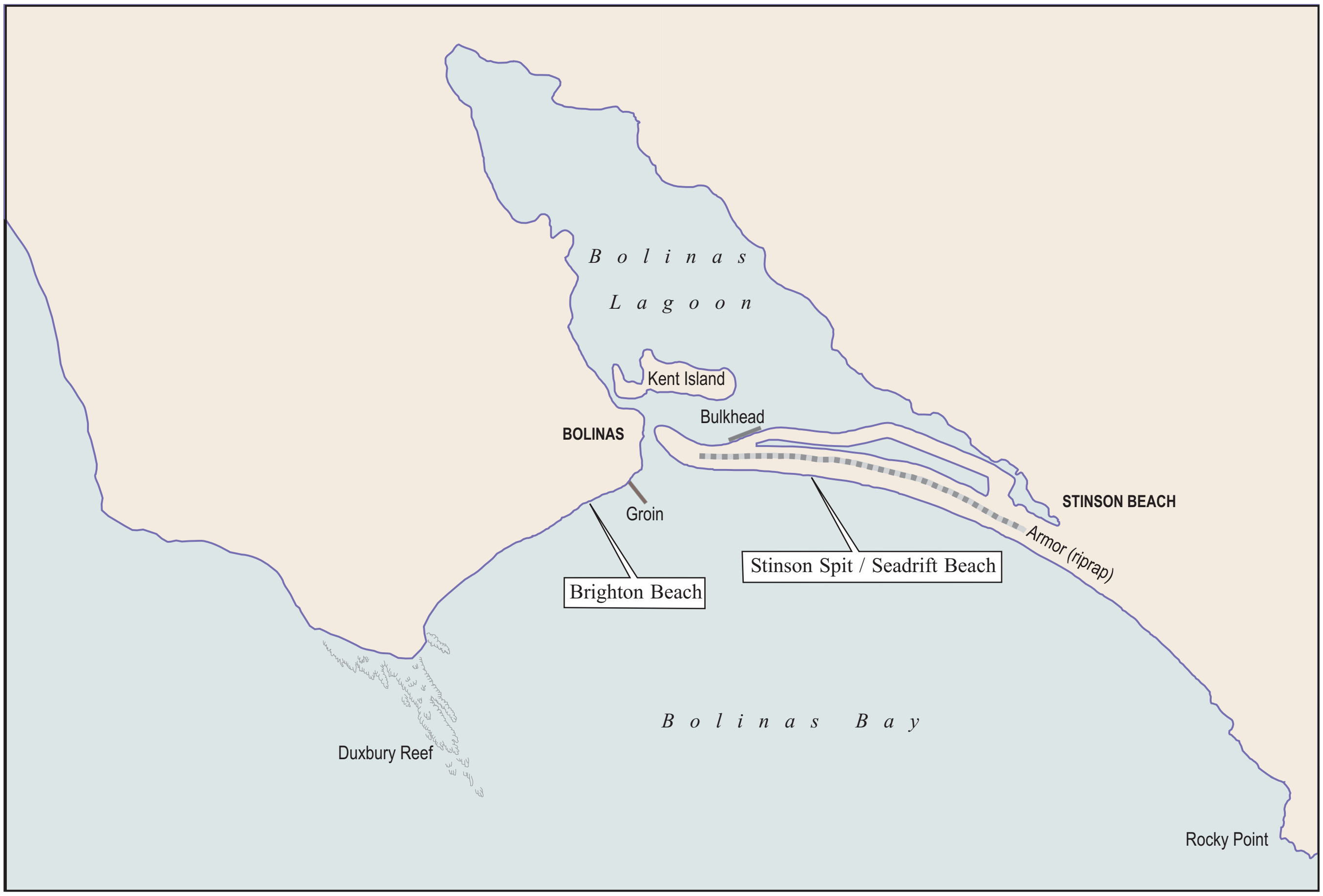

figure 1

Conceptual Littoral Sediment Budget at Bolinas Inlet

Location Map

Project # 1686.03 LocMapV2. cdr

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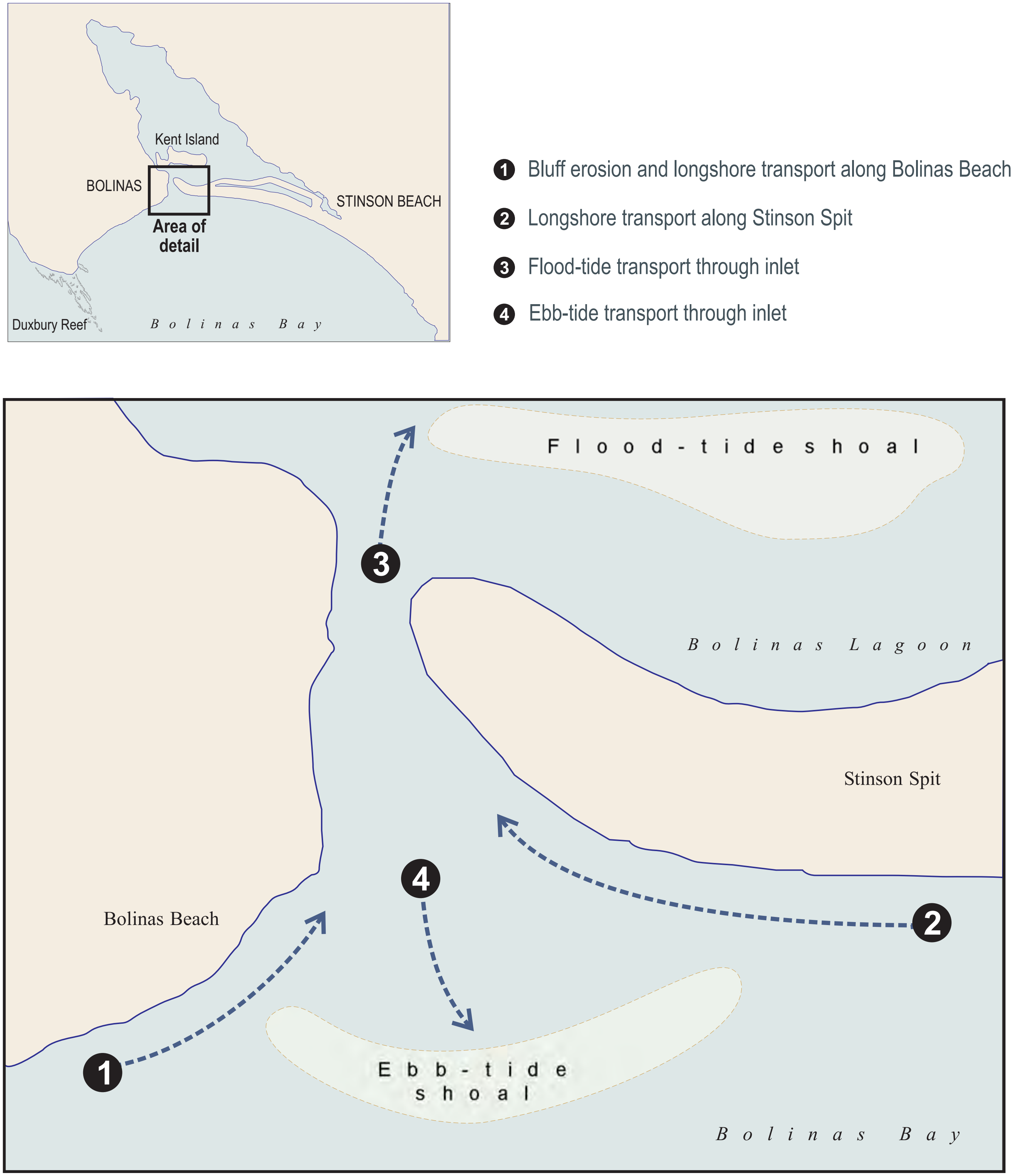

figure 2

Conceptual Littoral Sediment Budget at Bolinas Inlet

Conceptual Budget of Littoral Sediment

Proj. # 1686.03 ConcptBud.cdr

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Source: AirPhoto USA; May 2003

figure **3**

Conceptual Littoral Sediment Budget at Bolinas Inlet

Erosion and Transport at Bolinas Bluffs

PWA Ref# 1686.03

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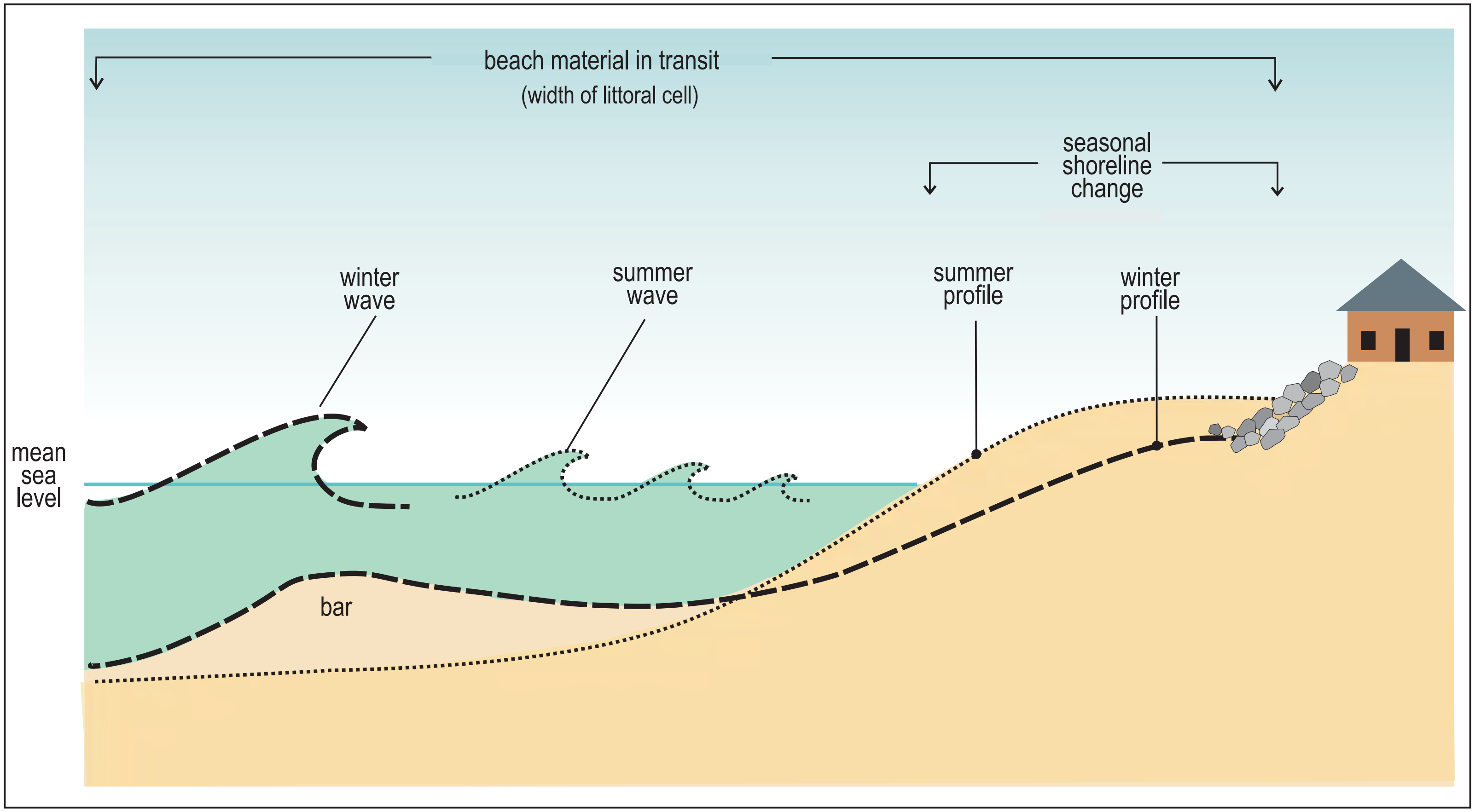

figure 4

Conceptual Littoral Sediment Budget at Bolinas Inlet

Seasonal Fluctuation in Beach Profile

Project # 1686.03 BeachProfileBolinas.cdr

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Note: Beach Width is defined as the distance between the Average High Water Line and the Vegetation Line

figure 5

Conceptual Littoral Sediment Budget at Bolinas Inlet

Shoreline Analysis- Transect Configuration

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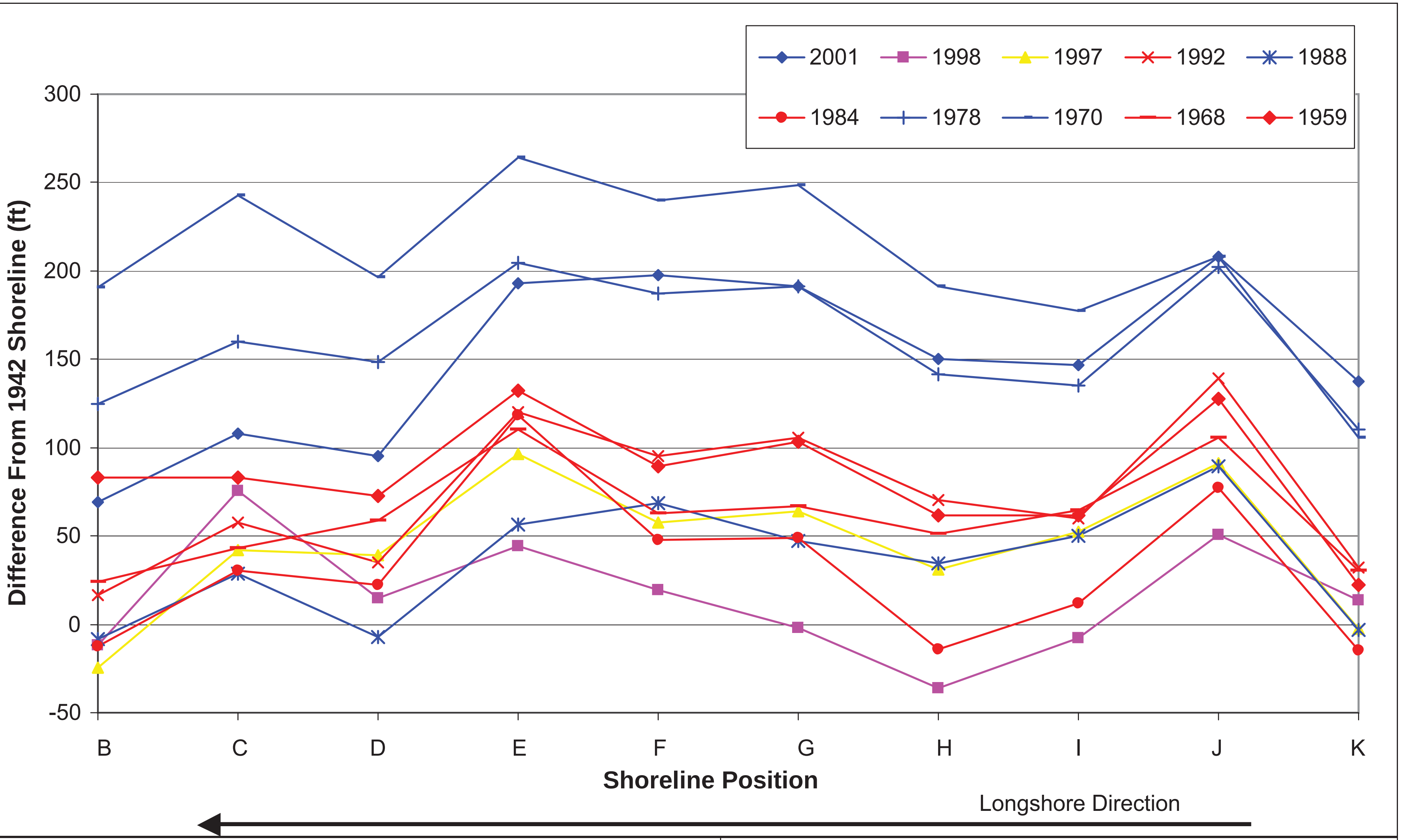

figure 6

Conceptual Littoral Sediment Budget at Bolinas Inlet

Distance from 1942 Shoreline

PWA REF # 1686.03

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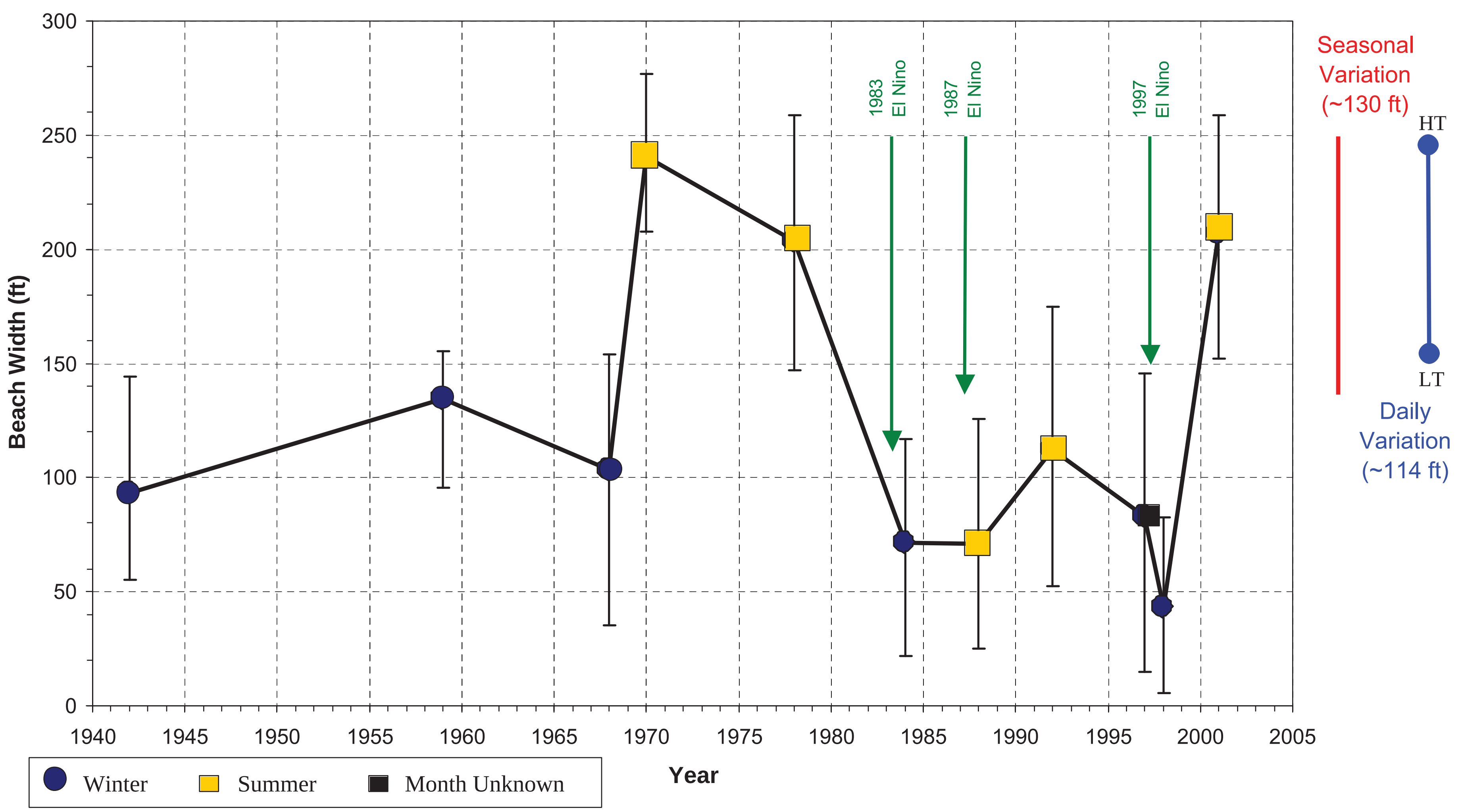

Notes: Beach Width is defined as the difference between the Average High Water Line and the Vegetation Line. Beach width computed with GIS tools from aerial photographs from Jan-1942, March-1959, May-1968, Aug-1970, Sept-1978, March-1984, Aug-1988, Aug-1992, 1997, April-1998 and 2001. Tide stage, time and date of 1942-1998 photos are unknown. Daily flucuation of exposed sand computed using 20:1 slope and 5.7-ft diurnal tide range. Seasonal fluctuations reported by Johnson (1973).

figure 7

Conceptual Littoral Sediment Budget at Bolinas Inlet

Average Change in Beach Width (1942- 2001)

PWA REF

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Looking toward bluffs and Warf Road from Bolinas Side of Inlet. Cobble derived from local erosion is in foreground.

Looking toward Kent Island from lagoon-side of Stinson Spit. Southwest bank of main channel is in foreground.

Source: PWA field visit on January 21, 2005.

f igure **8**

Conceptual Littoral Sediment Budget at Bolinas Inlet

Cobble Sediment at Inlet

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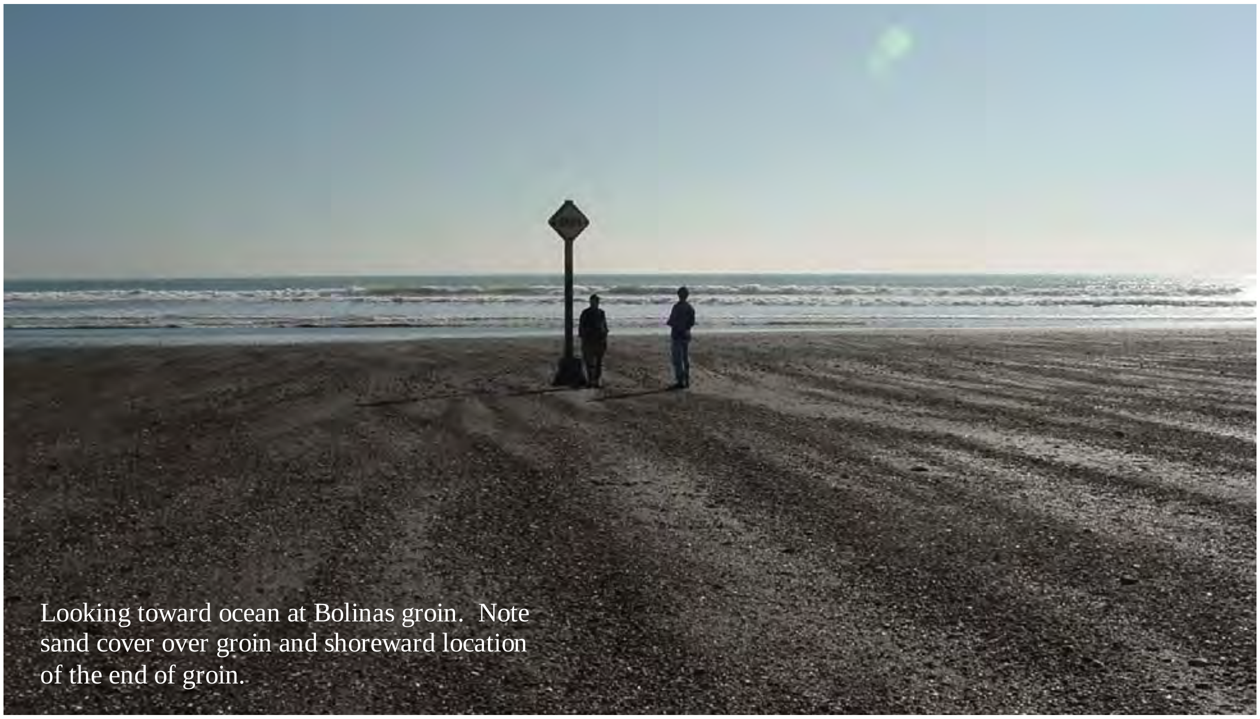

Looking toward ocean at Bolinas groin. Note sand cover over groin and shoreward location of the end of groin.

Looking toward bluffs at Bolinas groin. Note that sand has completely buried most of the groin – even during its low winter profile.

Source: PWA (Jan 21, 2005).

figure **9**

Conceptual Littoral Sediment Budget at Bolinas Inlet

Bolinas Groin Buried by Sand

PWA Ref# 1686.03

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Rip rap along Seadrift (near inlet). The relatively low beach elevation exposes the toe of the structure to wave action at high tide.

Dislodged rock at toe of structure.

Note: Low beach elevation exposes
Source: PWA (Jan 21, 2005)

f igure **10**

Conceptual Littoral Sediment Budget at Bolinas Inlet

Dislodged Rock at Rip Rap

PWA Ref# 1686.03

PWA

Note: End of bulkhead (looking south).
Source: PWA (Jan 21, 2005)

figure **11**

Conceptual Littoral Sediment Budget at Bolinas Inlet

Bulkhead on at Seadrift

PWA Ref# 1686.03

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