DRAFT
BROAD BEACH RESTORATION PROJECT
COASTAL PROCESSES

by

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Submitted to

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BROAD BEACH RESTORATION PROJECT
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1.0 INTRODUCTION

The objective of this report is to summarize oceanographic conditions (waves and tides) and coastal processes (beach width changes, sand transport along and across the beach) and to discuss the longevity of the proposed 600,000 cyd (cubic yards) of beach nourishment sand at Broad Beach.

The proposed project involves placing 600,000 cyd of sand with a commitment to perform one major re-nourishment event (450,000 cyd) along Broad Beach to create a wide beach backed by a system of sand dunes to protect the existing properties (homes and septic systems). The nourishment sand will be dredged and transported from offshore of Dockweiler Beach in Los Angeles County or from the sand trap at the mouth of Ventura Harbor or from offshore of Trancas Beach in the City of Malibu. Sand for dune construction may be dredged from a deposit offshore of Broad Beach near the Trancas Creek mouth (100,000-150,000 cyd). After placing the sand on the beach, the project will also include a maintenance component (annually or biannually), which involves backpassing 20,000-25,000 cyd of sand from the eastern reach to the western reach in order to maintain the nourished sand and prolong its residence time. The second nourishment event of 450,000 cyd of sand would occur when erosion leads to substantial narrowing of the newly created beach, estimated to occur 5 to 10 (or more) years after the initial nourishment. The proposed project does not involve further beach nourishment after the second event.

An additional key part of the project would be the permanent validation of the existing emergency revetment, which was constructed with substandard sized boulders of ½ to 2 tons and was not keyed into the bedrock or deeply into the beach, as is typically done with such structures. The question is whether the existing revetment would be able to withstand wave forces when the beach has eroded in 10 to 20 years or would fail to protect the existing homes and septic systems.

Broad Beach was wide during the late 1960s and 1970s, and it remained so well into the 1980s, when residential development was ongoing. Most of the properties were built between 1972 and 1989 when the beach was still wide. However, several storms from the early 1980s through the present have caused severe erosion: the 1982-1983 El Niño storms, wave storms in 1988 and 1993, the 1997-1998 El Niño storms, and storms during the winter of 2007-2008. During the El Niño of 1997-1998, many of the homes were threatened, causing many homeowners to construct temporary sand bag revetments to protect their homes. In December 2009, there was a significant narrowing of the beach due to a wave storm attack, resulting in failures of the existing temporary emergency sandbag revetments. As a result, an application was submitted to the California Coastal Commission (CCC) to obtain an emergency Coastal Development Permit (CDP) to implement an interim shore protection measure to halt the critical erosion until a longer term project was in place. During the December 2009 emergency, a temporary rock revetment was considered, and in early 2010, a 4,100-foot-long temporary rock revetment, permitted up to 2013, was constructed along Broad Beach. The CDP requires that the applicant either remove the emergency revetment, or complete an application for a regular CDP in order to have the emergency revetment considered permanent.

This project was designed by Moffatt & Nichol and is described in detail in M&N (2010, 2012a,b). This report is based on reports and studies submitted by Moffatt & Nichol (M&N) in cooperation with Everts Coastal in April 2010, April 2012, and June 2012. Other references are also used and referenced as appropriate. Most of the figures and tables in this report were extracted from M&N reports (2010, 2012a,b), as well as from other sources. Whenever appropriate, these sources are referenced, either in the figure caption or in the text.

1.1 DESCRIPTION OF PROJECT SITE

Broad Beach is located in the City of Malibu, California, and is within the western portion of Los Angeles County. Broad Beach is approximately 6,000 feet long and extends from Lechuza Point in the west to Trancas Creek in the east (Figure 1-1). The beach faces south-southwest (210º), and is bordered by El Matador State Beach to the west, Pacific Coast Highway

(PCH) and the Santa Monica Mountains to the north, Zuma Beach to the east, and the Pacific Ocean to the south.

The westernmost 1,000 feet of Broad Beach are primarily occupied by rocky intertidal lands (Figure 1-2). The beach is narrowest on its west end, becoming increasingly wider to the east. The beach is accessible to residents and the public, primarily during low to moderate tides, but it is inundated at medium to high tides in all areas except for the easternmost few hundred feet (Figures 1-3 and 1-4).

There are 114 residences and a beach club adjacent to and north of the beach. The base of each home is approximately 10-15 feet above the water level. The older homes on the east end are set back approximately 200-250 feet from the beach, while most of the newer homes are set back approximately 50-100 feet. In February 2010, an emergency rock revetment was installed in front (south) of 79 of the residences in the middle portion of Broad Beach (Figure 1-3). Most of the septic systems are located in the remnant dunes between the homes and the revetment.

Broad Beach is currently narrow and backed by the existing emergency revetment and existing homes. The homes in the eastern part of Broad Beach are relatively well set back from the beach and revetment. Broad Beach Road, which is located at the toe of the bluff, provides access to most of the homes. Pacific Coast Highway runs along the top of the bluff. Public access to Broad Beach is available from Zuma Beach County Park and two vertical access points from Broad Beach Road.

The sand exiting from area creeks is transported primarily to the southeast by the wave-induced longshore current. A littoral cell is defined as a geographical area with a complete cycle of littoral sand sources, transport paths, and sinks (Inman and Frautschy, 1965). Each littoral cell consists of sub-cells. The Zuma sub-littoral cell extends alongshore from Point Mugu to Point Dume (Orme et al., 2011). In this study, we refer to the stretch of coastline between Lechuza Point and Point Dume as the Zuma sub-littoral cell (Figure 1-6).

1.2 NATURAL SAND SUPPLY SOURCES

The geology of the region is dominated by the interaction of the very large Pacific and North American tectonic plates. While in many parts of California, these two plates are sliding past each other (NW-SE) along the San Andreas Fault, in the greater Los Angeles-Inland Empire area, the two plates are colliding in a north-south direction, which has resulted in the formation of the transverse ranges, of which the Santa Monica Mountains are a part. The Santa Monica Mountains are structurally a broad east-west oriented anticline. The mountains are primarily composed of sandstone, siltstone, and shale of the Topanga and Vaqueros Formations, with minor amounts of volcanic and dioritic rocks. These extremely folded and faulted sedimentary rocks are easily erodible and supply much sediment to the adjacent drainages during wet winters. The primary drainages in the area are Trancas Creek and Zuma Creek, which are both east of Broad Beach, and Arroyo Sequit, Little Sycamore Creek, Deer Creek, and Big Sycamore Creek, which are all west of Broad Beach (Figure 1-5).

The sand exiting from area creeks is transported primarily to the southeast by the wave-induced longshore current. The relatively small watersheds of these creeks appear to contribute approximately 30,000 to 40,000 cyy of sediment to this system, with Trancas and Zuma Creeks contributing an additional 8,000 cyy to the Zuma littoral subcell downcoast from Broad Beach (Everts Coastal, 2009; TerraCosta, 2008).

Sediment is also supplied to the ocean through the erosion of local bluffs, with bluff erosion estimated to contribute an average of 7,000 cubic yards per year of sand between Point Mugu and Point Dume, a reduction of approximately 12% (1,000 cubic yards per year) from historic levels due to the armoring of approximately 3,500 feet of bluffs on this stretch of coast (Patsch and Griggs, 2007).

Historically, another major source of sand into this littoral cell has been the construction of Pacific Coast Highway (PCH) along the northern Malibu coast, which contributed an estimated 1.2 million cubic yards of sand that were used for fill or the disposal of excess material. The sand from the initial construction of PCH and another approximately 150,000 cubic yards of sand from its subsequent maintenance were placed into the system as offshore disposal of fill from cut slopes (Patsch and Griggs, 2007). Thus, the historic width of Broad Beach and other Malibu beaches may have benefited substantially from this artificial input of sediment.

An additional potential sand source for this reach of coast would be sand from the Santa Barbara Littoral Cell, some unknown portion of which may bypass Mugu Submarine Canyon. Mugu Submarine Canyon captures the highest portion of longshore sediment transport in its vicinity of any submarine canyon in California. Based on a study prepared for the U.S. Army Corps of Engineers, as much as 90% of the longshore transport at this location enters the canyon and is lost from a longshore transport rate of approximately 1,065,000 cyy at this location (Moffatt & Nichol, 2009). However, various studies disagree on the exact quantity of sediment, if any, that passes Mugu Submarine Canyon; thus, the contribution from this source is uncertain.

1.3 BEACH NOURISHMENT SAND SOURCES

Possible sources of beach nourishment sand include 1) the Central Trancas dredge site offshore of Broad Beach, or/and 2) the Ventura Harbor sand trap in Ventura County, or/and 3) dredge sites offshore of the City of Los Angeles (Dockweiler Beach offshore dredge site). Figure 1-7 shows the locations of these sites, and short descriptions are given below:

1. The Central Trancas dredge site encompasses 23.4 acres located approximately 1,350 feet offshore of Broad Beach in 45 to 60 feet of water. The distance to the Central Trancas dredge site from shore is approximately 3,000 feet.
2. The Ventura Harbor sand trap area includes a dredge site of approximately 11 acres located in 25 to 40 feet of water adjacent to and north of the breakwaters of Ventura Harbor (Figure 1-8). Ventura Harbor is located next to the mouth of the Santa Clara River, about 28 miles southeast of the Santa Barbara harbor and six miles north of the Channel Island harbor. Ventura Harbor is an artificial commercial and recreational harbor developed by the Ventura Port District in 1963. An offshore breakwater was constructed in 1971 to form a sand trap to reduce shoaling at the entrance channel.

Presently, the Los Angeles District of the U.S. Army Corps of Engineers (USACOE) maintains the navigational features in the harbor and performs periodic dredging. The harbor and the local shoreline are situated such that waves originate from the west, causing sediment to move predominantly in a downcoast direction for most of the year. The sand has accumulated at a rate that requires annual dredging of the entrance channel to maintain safe navigation depths of 20 to 30 ft below Mean Lower Low Water (MLLW). Dredged material has been deposited primarily at McGrath State Beach, south of the Santa Clara River. If the McGrath site is unavailable, dredged material is usually deposited at South Beach. On average, 600,000 cyd are dredged from the harbor sand trap.

3. The Dockweiler Beach offshore dredge site encompasses 115 acres located approximately 2,775 feet offshore of Dockweiler Beach in 40 to 45 feet of water. Dockweiler Beach is three miles long. The beach is located at the western terminus of Imperial Highway in Playa del Rey. From 1969 through 2007, about 1,280,000 cyd of sand were placed on Dockweiler Beach from the Marina Del Rey harbor dredging operation over six dredging events (USACOE, 2011a)

Figure 1-1. Broad Beach location map (from Moffatt and Nichol, 2010).

Figure 1-2. Westernmost (rocky intertidal) portion of Broad Beach.

Figure 1-3. Central portion of Broad Beach and emergency revetment installed in February 2010.

Figure 1-4. Easternmost (widest) portion of Broad Beach.

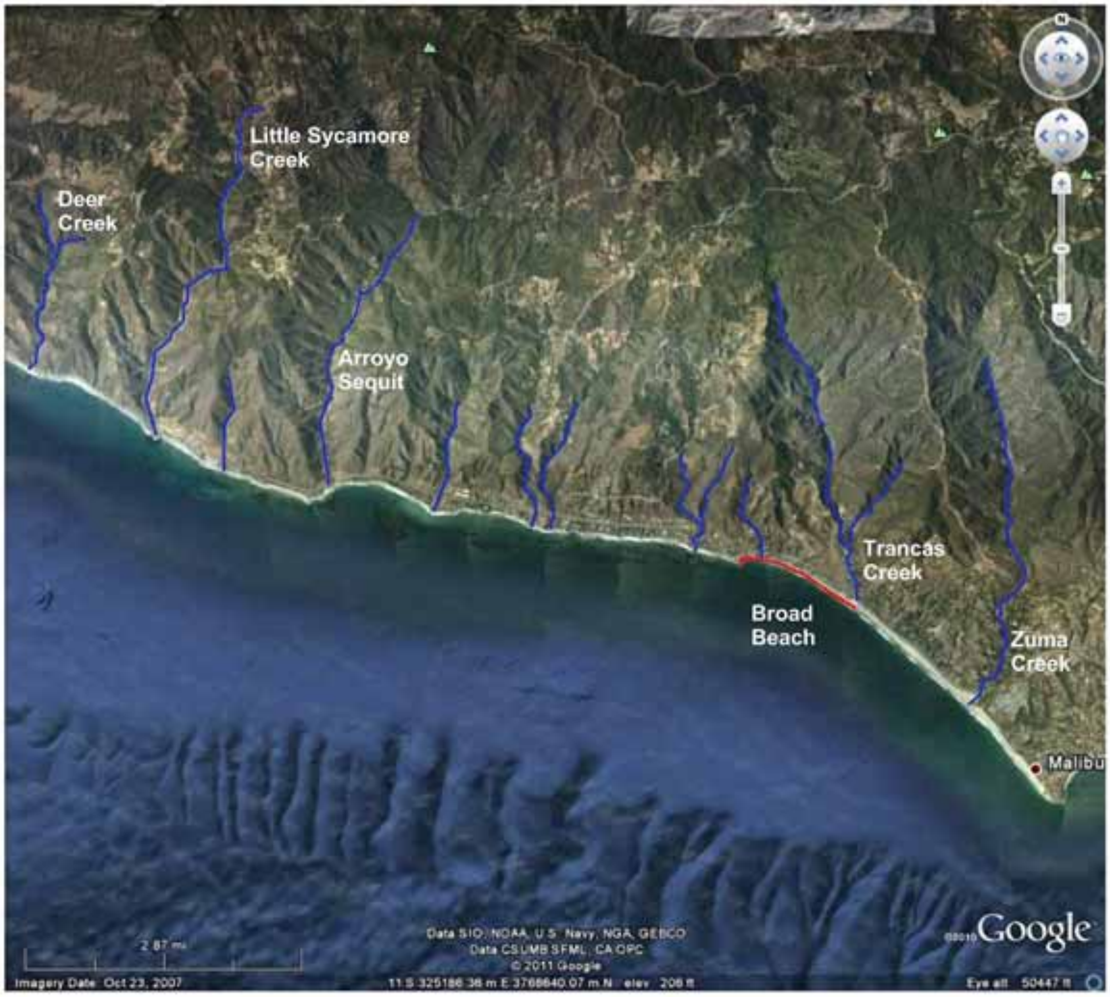

Figure 1-5. Major and minor creeks near Broad Beach that supply sand to Zuma Littoral Cell.

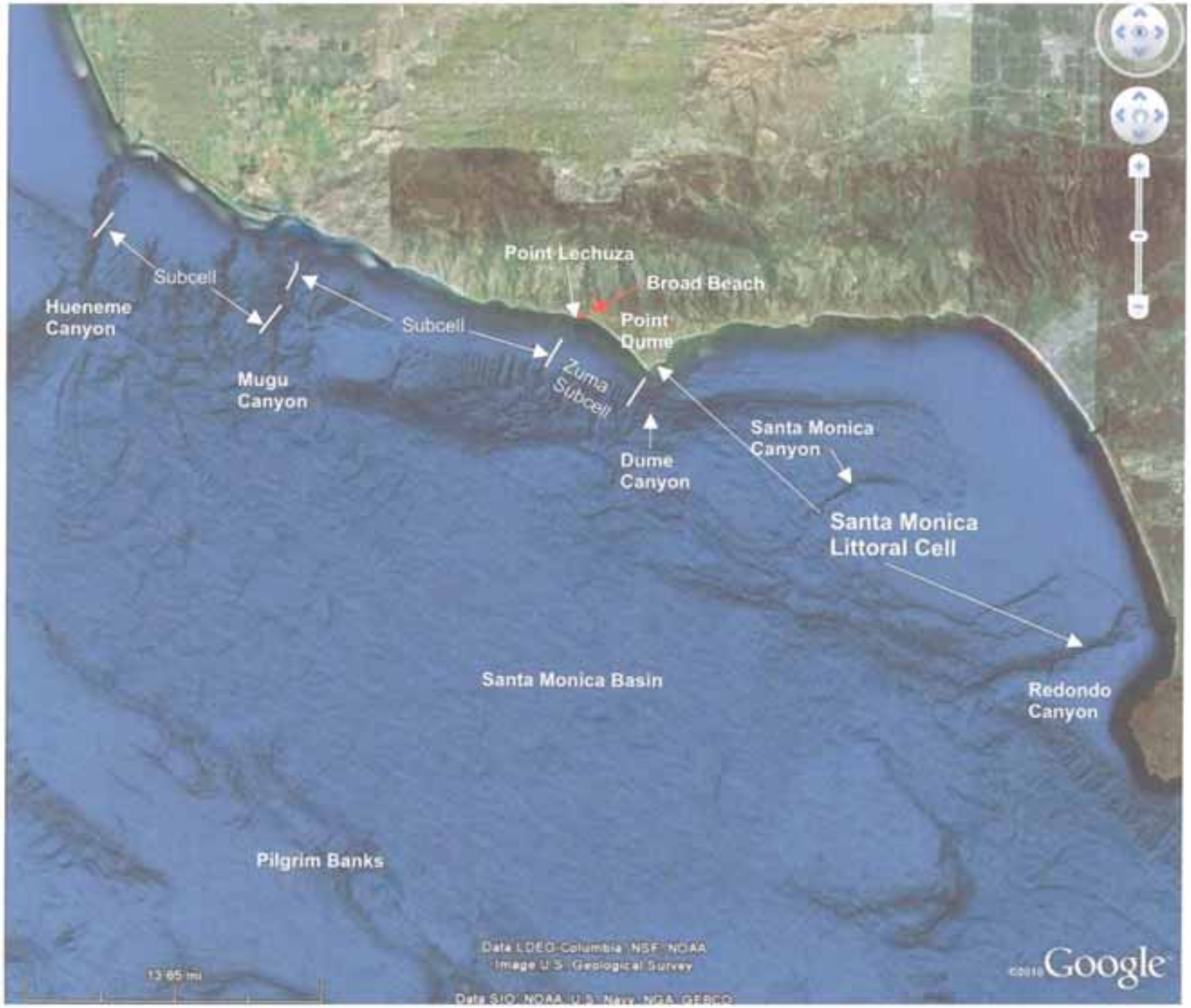

Figure 1-6. Littoral cell locations in relation to Broad Beach.

Figure 1-7. Location of borrow sites at Dockweiler, Central Trancas, and Ventura Harbor sand trap.

Figure 1-8. Site location map of Ventura Harbor.

2.0 DESCRIPTION OF WAVES AND TIDES

2.1 DESCRIPTION OF WAVE CLIMATE AT BROAD BEACH

Waves provide the largest source of energy to the coast of California and are responsible for sand transport and beach erosion, as well as coastal flooding and damage. This section reviews the relevant properties of waves off Broad Beach. Ocean waves in Southern California fall into three main categories:

1. Northern Hemisphere Swell: Waves generated in the Northern Hemisphere that propagate into Southern California waters,
2. Southern Hemisphere Swell: Similar waves generated south of the equator, and
3. Local Seas: Relatively short-period waves generated within the Southern California Bight by winds.

Broad Beach is sheltered from deep-ocean waves by numerous offshore islands and shoals (Figure 2-1); thus, only waves from certain directions reach the project site (Pawka, 1982 and 1983). This is due to the sheltering effect of various offshore islands, including Santa Cruz, Santa Rosa, San Miguel, Santa Catalina, and San Clemente.

The largest windows from which waves can reach the shoreline at the project site are from the west and southwest at an angle of 263°-220° (from true north). The predominant summer wave direction is largely open from the south (from 168°-220°), as shown in Figure 2-1.

The wave climate has varied over the years. For example, wave events tended to be moderate between the mid-1940s and mid-1970s, when La Niña (cool water temperature periods of low wave energy and low rainfall) conditions were typical. The principal wave energy from the winter Aleutian low-pressure systems did not track far enough south to reach Southern California. Summer swells were intermittent and came from distant Southern Hemisphere storms. The wave climate changed over the next 20 years from 1978 to 1998 with the onset of El Niño weather conditions (periods of local warm water and corresponding large storms and high rainfall). There was an increase in the number and intensity of extreme wave events. High-energy winter waves approached the coastline from the west or southwest, and the summer waves were from hurricanes off Central America. More recently, between 2000 and the present, the wave climate has generally been mild.

Figure 2-1 shows the locations of existing wave buoys at Stations 46025 and SIO-102. Wave measurements were made by the National Oceanic and Atmospheric Administration (NOAA) and Scripps Institution of Oceanography (SIO) using these buoys, designated as NDBC (National Data Buoy Center) and CDIP (Coastal Data Information Program) buoys, respectively. These measurements were made in deep water at depths of over 100 m.

Figures 2-2 and 2-3 show a time-series plot of daily maximum significant wave heights (Hs) and average wave period (Ta) obtained from Buoy 46025. Buoys 46025 and SIO-102 are sheltered from North Pacific waves by the northern Channel Islands, but are exposed in the south to about the same degree as Broad Beach.

Figures 2-4 and 2-5 show the distribution of significant wave height and direction for the measurements at Buoy 46025 and Buoy SIO-102, respectively.

O'Reilly and Flick (2008) used wave information for the California coast available from the Coastal Data Information Program (CDIP) to determine the wave-related causes of the unusual erosion observed at Broad Beach during the winter and spring of 2007-2008. The data consists of nearly eight years of hourly wave height, period, and direction calculated at 100 m (330 ft) intervals along the California coast, including the area off Broad Beach. The locations of these Modeling and Prediction (MOP) points are shown in Figure A-1. O'Reilly and Flick used these data to estimate the directions of longshore sand transport (westward or eastward) and cross-shore sand transport (onshore or offshore) from 2000 to 2008 along Broad Beach. Their results are presented in Appendix A.

The simulation of the wave data in front of Broad Beach by O'Reilly and Flick (2008) is very helpful for understanding its wave climate. In general, waves at Broad Beach are mild. Most of the time, they are less than 4 ft (1.25 m) high, with only a few wave storms having reached heights greater than 7 ft (2.5 m). Between 2000 and 2008, the number of hours per year that wave heights were greater than 5 ft ranged from 0 to 103, with an average of 52 hours.

2.2 TIDES AND SEA LEVEL

The tide is the change of ocean water level caused by the astronomical forces of the moon and sun. Tidal fluctuations are superposed on sea level. The tide is predictable and can be decomposed into a set of constituent frequencies near 1 and 2 cycles per day, each having a given amplitude and phase at any location. Substantial fluctuations in the tidal range occur at 2 cycles per month (Spring and Neap), 2 cycles per year, every 4.4 years, and every 18.6 years. On the Broad Beach coast, the tide is mixed semidiurnal with nearly equal semi-daily and daily components. The highest monthly tides in the winter and summer are higher than those tides in the spring and fall as a result of lunar and solar declination effects. The extreme monthly higher-high tides in the winter tend to occur in the morning. The average value for the tide range is about 2 m (6 ft). The extreme observed high tide is about 7.8 ft, MLLW and the extreme low is -2.7 ft, MLLW. The mean sealevel (MSL) is about 2.8 ft (1983-2001 Epoch).

Seasonal sea level at Broad Beach, as determined from monthly mean values, tends to be highest in the fall and lowest in the spring. Local warming or cooling resulting from offshore shifts in water masses can alter the average sea level by several tenths of a foot over periods of several months (e.g., during El Niño years; Reid and Mantyla, 1976). Tidal elevations are computed at 19-year intervals (National Tidal Datum Epoch).

Storm surges, which result from the effects of lower atmospheric pressure and higher winds during storms, increase the water level above the tide. Together, tides, storm surges, and sealevel changes determine design water levels. The design water level is important for coastal processes and engineering, since it determines how high and how far shoreward the effect of breaking waves can reach. For example, if sea levels are unusually high because of a combination of factors, including high tides, storms, and elevated sea levels from El Niño conditions (such as during the winters of 1982-83 and 1997-98), large waves can be far more effective in causing flooding, structural damage, beach erosion, and cliff failure than under normal conditions. The storm-surge component of sea level is a maximum of 0.35 cm (1 ft).

2.3 SEALEVEL RISE

Together, tides, storm surges, and sealevel changes determine design water levels. Due to global warming caused by an increase in the atmospheric concentration of carbon dioxide, sealevel will rise. Predicted changes in sealevel rise based on six numerical models indicate that the increase in sealevel rise over the coming 100 years would be between 0.18 m and 0.59 m (IPCC [Inter-governmental Panel on Climate Change], 2007). The likely estimate is 0.5 m/century (1.6 ft/century). The IPCC consists of 35 international scientists who are distinguished in their respective fields.

Estimates of future sealevel rise for the next 100 years due to global warming vary between 0.6 ft/century and 1.6 ft/century (IPCC, 2007). Other changes that occur in MSL due to El Niño events and storm surges are of a similar order. Most damages to coastal structures and beaches are caused by large waves occurring at high water levels (Spring tide). However, the probability of such a coincidence of large waves and high water levels (tides) is small.

There are other estimates of sealevel rise based on the mid-range of predictions (California Climate Change Center, 2009); these estimates are 1 ft (12 inches) by 2050 and 3.6 ft (37 inches) by 2100 (low to moderate rates of sealevel increase). The prediction with the highest rate of sealevel increase was made by the California Climate Change Center (2009): 1.5 ft (16 inches) by 2050 and 4.3 ft (52 inches) by 2100. The current rate of sealevel increase along the California coast ranges between 1.2 mm/year and 1.6 mm/year, based on data up to 2012.

Since this project will require state and federal agency approval, the following are regulatory agency policies regarding sealevel rise.

1. California State Coastal Conservancy Memo (2009). This policy statement includes the following directive: “Prior to the completion of the National Academies of

Science Report on sealevel rise, consistent with Executive Order S-13-08, the Conservancy will consider the following sealevel rise scenarios in assessing project vulnerability and, to the extent feasible, reducing expected risks and increasing resiliency to sealevel rise: 1) 16 inches (40 cm) by 2050; and 2) 55 inches (140 cm) by 2100." These numbers are the bases of what was used as the "highest rate of increase" prediction above.

2. Executive Order S-13-08. The executive order directs the California Resources Agency to request that the National Academy of Sciences convene an independent panel to complete the first California Sea Level Rise Assessment Report. The Final Sea Level Rise Assessment Report will advise how California should plan for sealevel rise. Additionally, the Executive Order states that prior to the release of the Final Sea Level Rise Assessment Report, all state agencies planning construction projects in areas vulnerable to future sealevel rise shall, for the purposes of planning, consider a range of sealevel rise scenarios for the years 2050 and 2100 in order to assess project vulnerability and, to the extent feasible, reduce expected risks and increase resiliency to sealevel rise. Sealevel rise estimates should be used in conjunction with appropriate local information regarding local uplift and subsidence, coastal erosion rates, predicted higher high water levels, storm surge, and storm wave data.
3. California Coastal Commission (2001). The California Coastal Commission published a paper entitled "Overview of Sea Level Rise and Some Implications for Coastal California" on June 1, 2001 (CCC, 2001). The paper recognized that the continued rise in sea level will affect almost all coastal systems by increasing inundation of low coastal areas and potential for storm damage, beach erosion, and beach retreat. Regarding implications, the report states that: 1) "In California, it is likely that a combination of hard and soft engineering solutions and retreat responses will be considered to address sealevel rise. There are situations where each response may be appropriate and well suited. In all coastal projects, it is important to recognize and accept that there will be changes in sea level and in other coastal processes over time."

4. The USACOE (2011b) released Engineering Circular (EC) No. 1165-2-212 in October 2011, which updated their prior EC (No. 1165-2-211) released in 2009 (USACOE, 2009) on the same topic. The EC provides guidance on the consideration of the direct and indirect physical effects of sealevel rise across the project life cycle for civil works projects. Specifically, projects must consider how sensitive and adaptable natural and managed ecosystems and human and engineered systems are to climate change and other related global changes.

The EC recommends consideration of three sealevel rise scenarios (low, intermediate, and high) over the project life-cycle. These scenarios are as follows:

- “Low” rate is the historic rate of sealevel rise extrapolated over the project life;
- “Intermediate” rate is between the low and high rate estimates based on moderate scientific predictions from scientists and the best that is known about the subject.
- “High” rate exceeds the upper bounds of IPCC estimates from both 2001 and 2007 to accommodate potential rapid loss of ice from Antarctica and Greenland, but is within the range of peer-reviewed articles released since that time.

Based on this information, in 2050 sealevel rise at Broad Beach will be 0.17, 0.42, and 1.2 ft, for low, intermediate, and high rates, respectively.

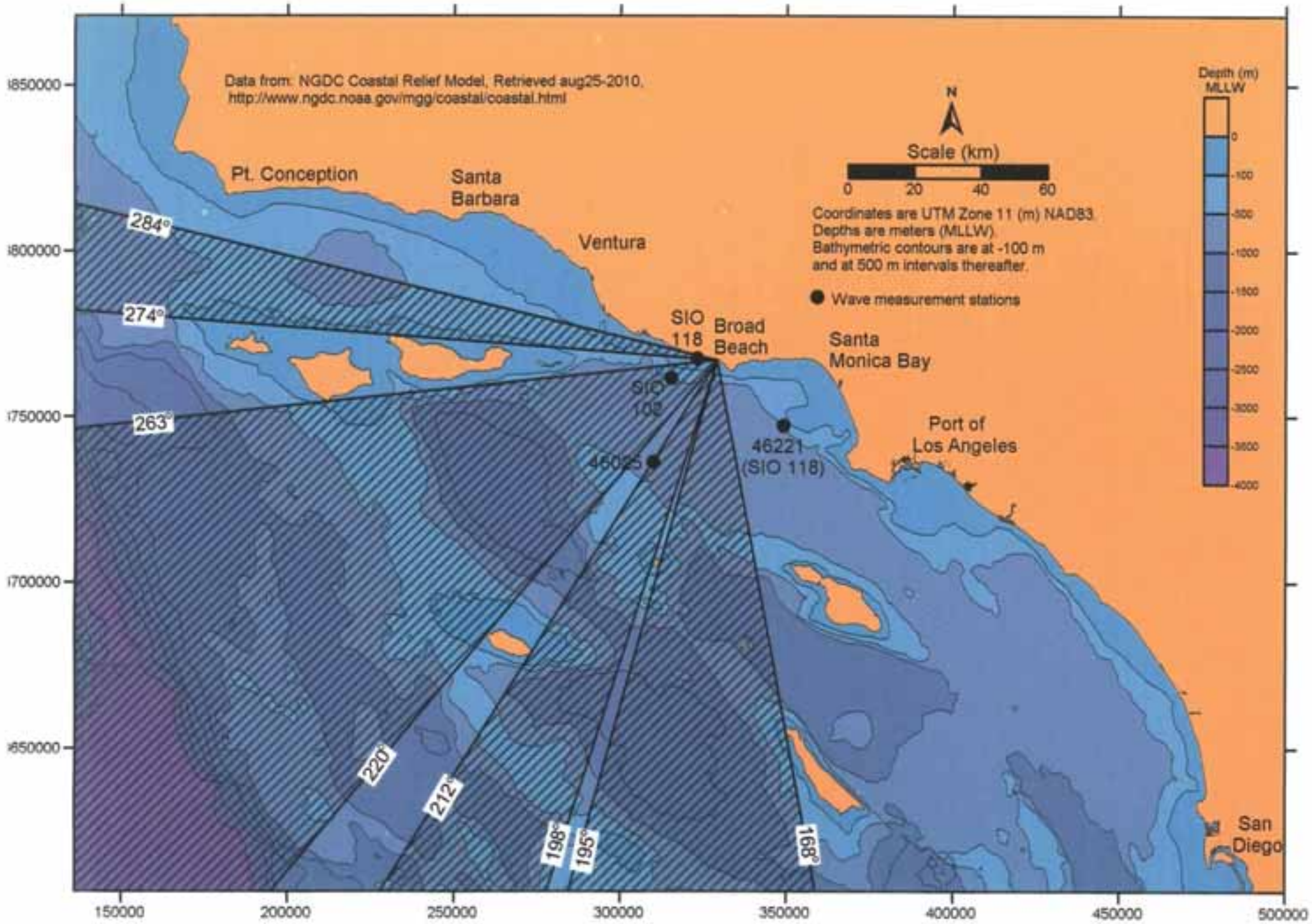

Figure 2-1. Wave exposure windows at Broad Beach and locations of NOAA and SIO wave measurement buoys.

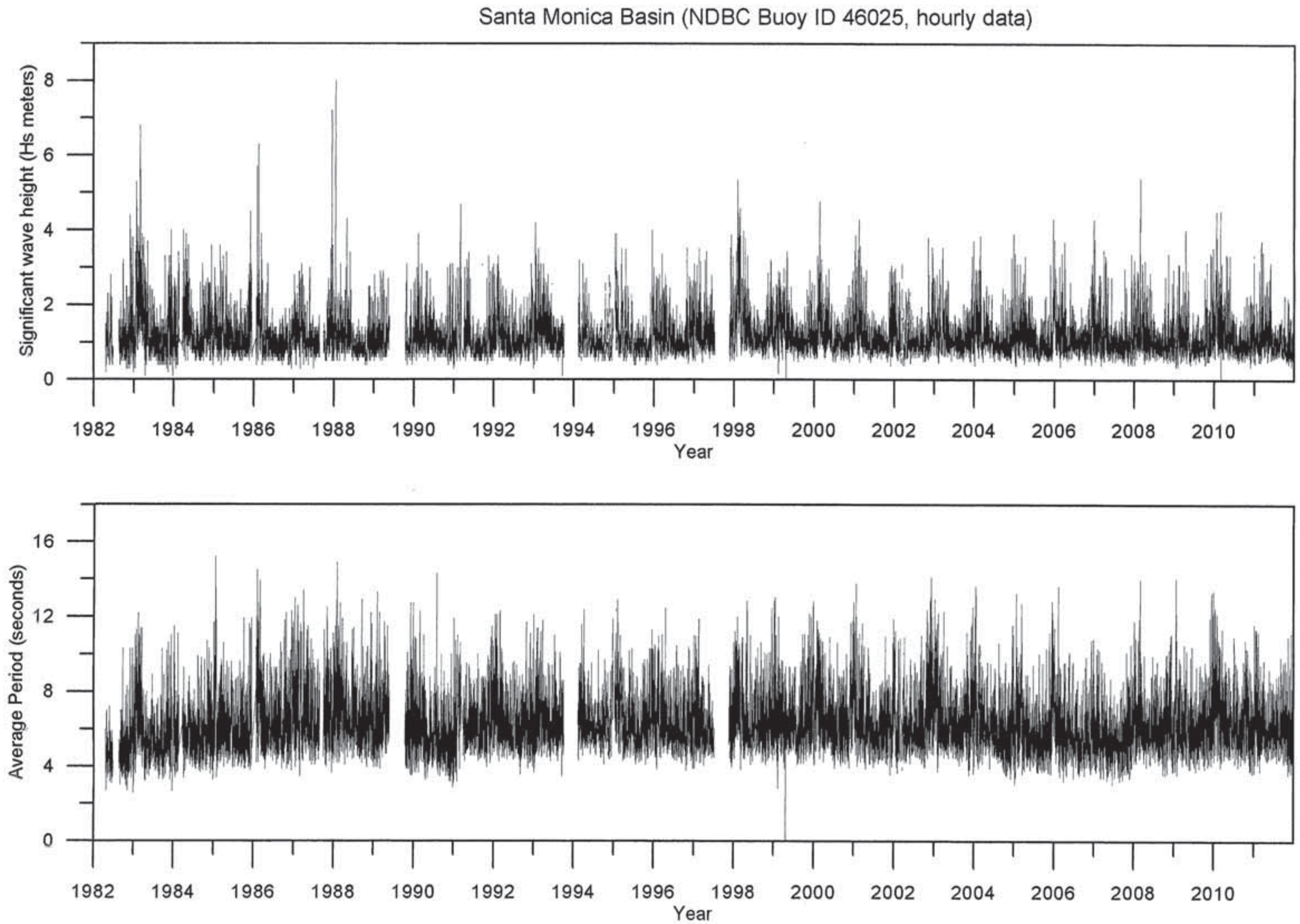

Figure 2-2. Time-series plot of significant wave height and period for NDBC Buoy 46025.

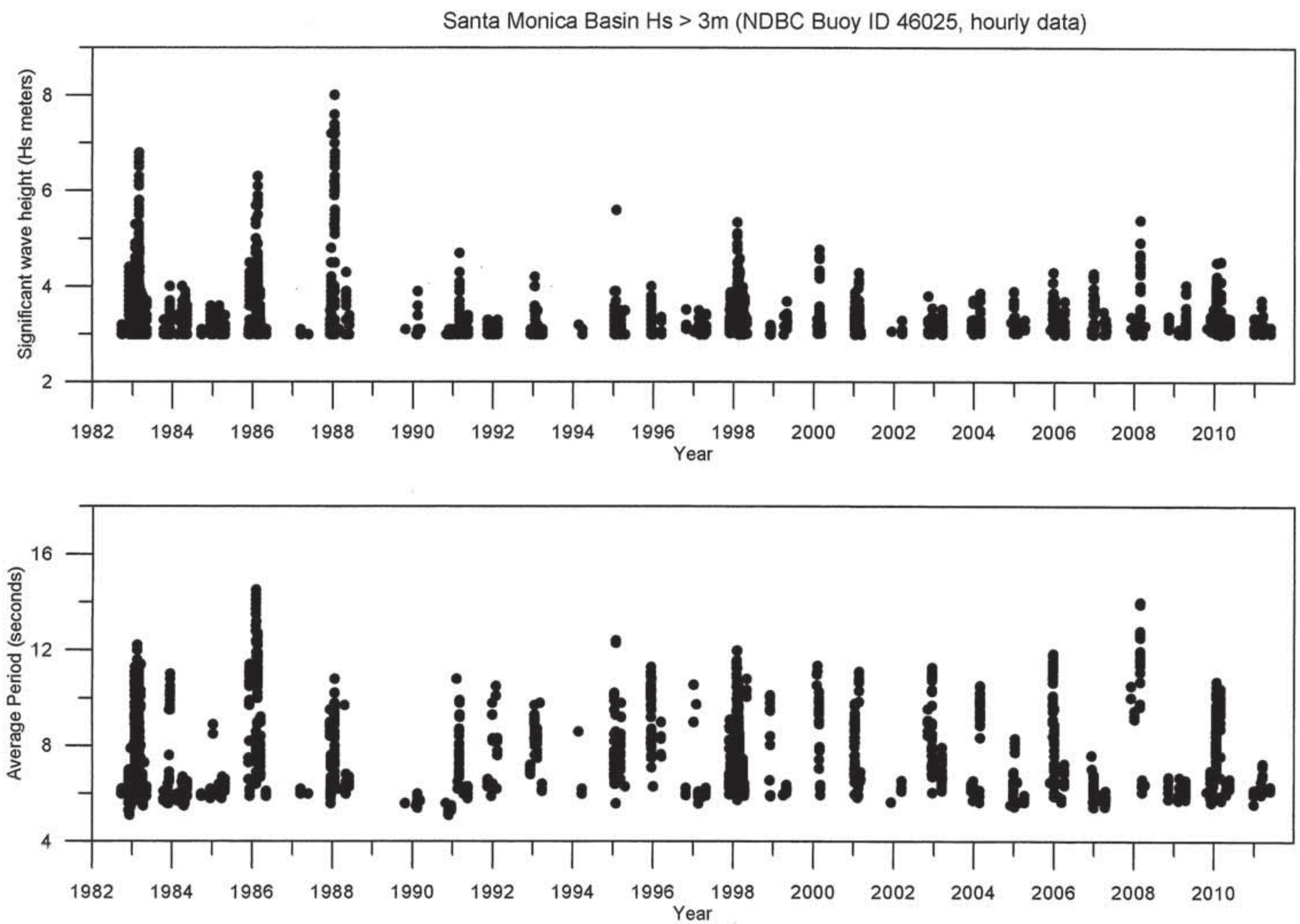

Figure 2-3. Time-series plot of significant wave height and period for waves greater than 10 ft (3 m) from NDBC Buoy 46025.

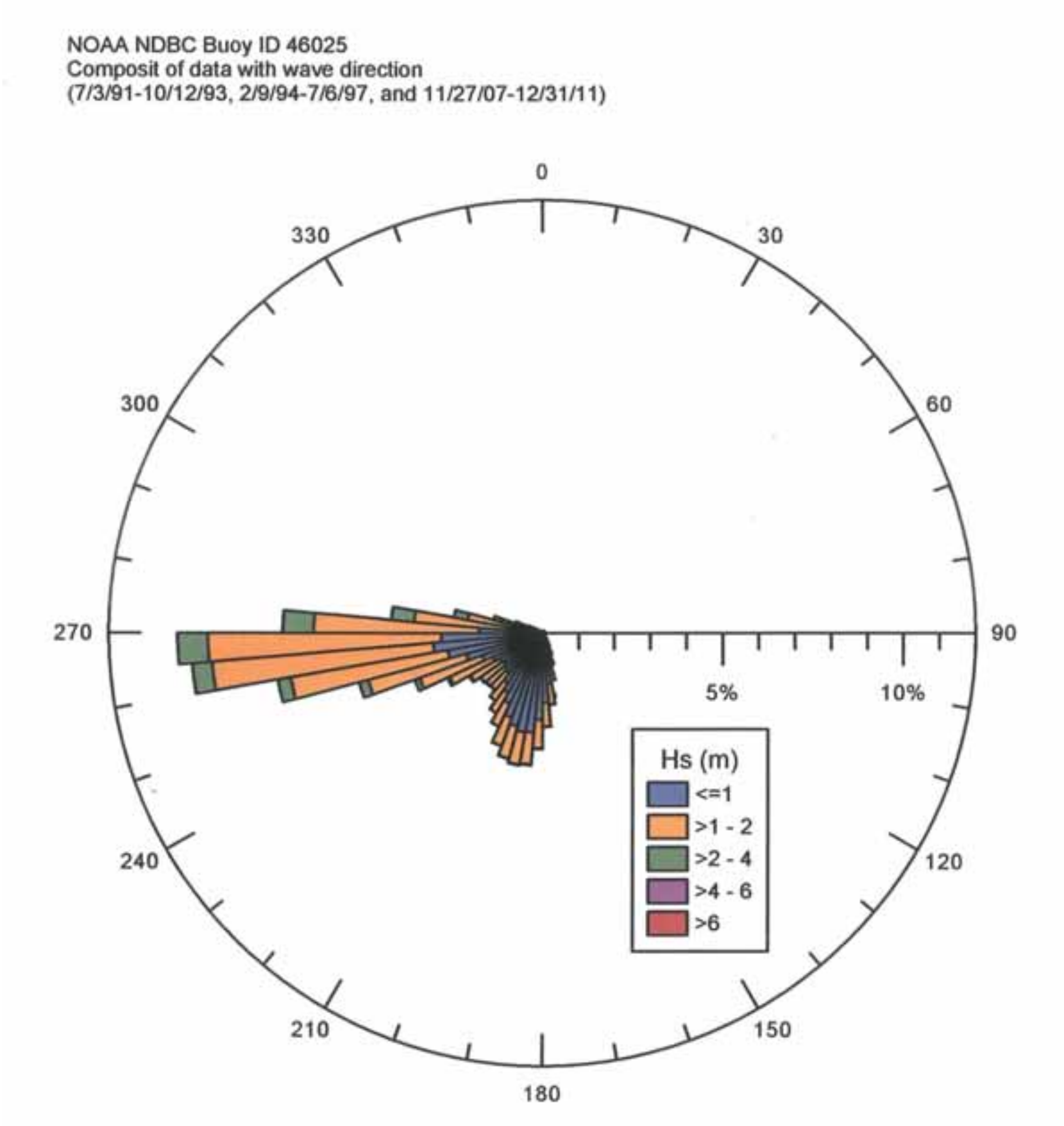

Figure 2-4. Distribution of wave height and direction at NDBC Buoy 46025.

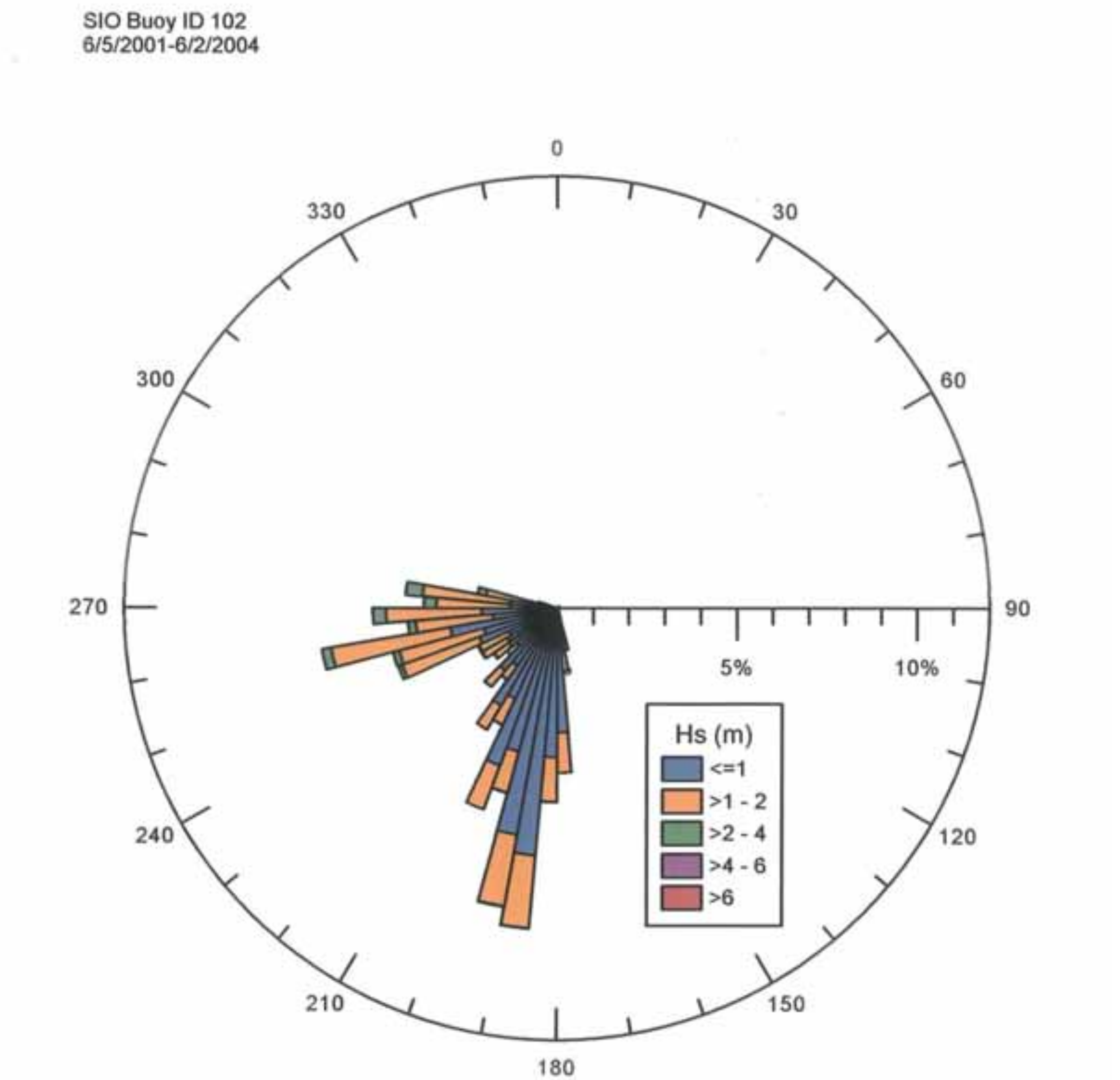

Figure 2-5. Distribution of wave height and direction at SIO Buoy 102.

3.0 HISTORICAL BEACH WIDTH AND PROFILE CHANGES

3.1 BEACH WIDTH

Moffatt and Nichol presented a study (M&N, 2010, 2012a,b) that addressed beach width changes at Broad Beach utilizing shoreline positions extracted from historic aerial images of beaches gathered from various sources. These photographs were first geo-rectified by being brought into a known geographic coordinate system using Geographic Information Systems (GIS) and common physical reference points. The shoreline was drawn along the wetted line of the beach to depict the shoreline position. An arbitrary baseline was set landward of all the shoreline positions, and beach widths at various locations were calculated from the baseline to the wetted shoreline. A total of 20 historical shorelines were analyzed between 1946 and 2009. Comparisons between these shorelines were made to demonstrate graphically the changes in shoreline points from one time interval to another.

The calculated beach width database was used to determine the average changes in beach width, seasonal beach width change rates, and historical minimum and maximum beach widths. The time-series of beach width was also used to estimate volumetric changes computed from beach profile changes between two dates.

Figure 3-1 shows the average shoreline changes at Broad Beach from 1946 until the present relative to the 1946 shoreline. The 1946 shoreline is set as the baseline (distance from 1946 shoreline at 1946 is 0). M&N concluded that: 1) there has been significant variation in the average beach width since 1946; 2) the beach at Broad Beach was at its widest point in the early 1970s, and since then it has experienced variable but declining width; and 3) variation in beach width does not appear to correspond to a uniform pattern.

In Figure 3-2, the linear regression line indicates that the beach has, on average, lost width at a rate of about two feet per year (2 ft/year) since 1970. The moving average line (red) indicates that the shoreline recession has been happening at a variable rate, but appears to accelerate in the 2000s. Figure 3-3 shows the average Broad Beach and Zuma Beach shoreline positions between 1945 and 2010. This figure also shows that some of the eroded sand from Broad Beach has been transported to eastern beaches (Zuma Beach).

Volumetric beach profile changes can be calculated from the equation:

$$V = A_b (h_b + d_s)$$

Where:

$A_b = S_c X_c$

S_c = mean shoreline position

X_c = alongshore length for the area of interest

h_b = height of berm

d_s = depth of closure

Figure 3-4 shows the sand volume changes for Broad Beach from 1946 through 2010. The average sand volume change between early 1970 and 2010 was about 21,000 cyy (yd^3/yr), while between 2004 and 2010, the sand volume change was about 35,000 cyy.

The Zuma sub-littoral cell extends from Lechuza Point in the west and Point Dume to the southeast. This sub-littoral cell includes Broad Beach, Zuma Beach, and Point Dume State Beach. A comparison of sand volume changes from 1946 to 2007, 1968 to 2007, and 1986 to 2007 is presented in Figure 3-5. Figure 3-5 illustrates the increasing loss of sand at the western end of the cell and the increasing rate of sand gain from west to east. Broad Beach is retreating because of negative sand balance.

3.2 SEASONAL AND LONG-TERM BEACH WIDTH CYCLES

Annual oscillations in beach width (seasonal cycles) are well recognized in California. In the fall and winter, the beaches erode as a result of winter storms, while in the spring and summer, the beaches accrete as a result of the milder wave climate.

Climatic events such as the El Niño-Southern Oscillation (ENSO) affect wave climate on a worldwide scale by altering global atmospheric circulation paths (Inman et al., 1996). Along the west coast of the United States, this brings a more intense wave climate. El Niño also modifies rainfall, causing more intense flooding and maximum sediment yield on the west coast. Despite inputs of fluvial sediment, exposed beaches typically experience net erosion by intense storm waves.

Along the Southern California coastline, decades of relatively stable, mild wave climate are interrupted by El Niño events, which are characterized by groups or clusters of intense storms and heavy rainfall. The El Niños of 1982-83 and 1997-98 eroded beaches that had been stable for many years.

El Niño conditions, which appear every 2 to 7 years in varying strengths, represent a "warm" state in the tropical Pacific Ocean. This alternates with a "cool" state called La Niña, where these circumstances are essentially reversed. Neutral, or normal, conditions represent a third state, which shows neither anomalous warming nor cooling.

In Southern California, only one-half of all El Niño events are associated with above-average storminess and the attendant rainfall and high waves (Flick and Willis, 1997). The other half bring normal, and sometimes even below normal, rainfall. This means that El Niño conditions alone do not guarantee that there will be severe winter weather in Southern California, but they do increase its probability substantially (Flick and Willis, 1997).

Long-term trends lasting decades or more are not well understood (Orme et al., 2011). These trends vary from one beach to another. Factors that may affect long-term changes in beach width include ENSO events and the large waves that occur during normal conditions. Many beaches that eroded as a result of the 1982-83 cluster storms took a long time to recover, and some of them have not recovered yet (e.g., the City of Del Mar beach). Orme et al. (2011) studied changes in beach width along five littoral cells for a period of 56 to 77 years prior to 2002. These beaches were located in the Santa Barbara, Zuma, Santa Monica, San Pedro, and Oceanside cells. The objective of the study was to identify trends in beach width over a period of several decades. Long-term changes in beach width differ from one beach to another for various reasons, including a response to El Niño storm events in 1978-1980, 1982-1983, 1992-1993, and

1997-98; the presence of structures (jetties, groins, breakwaters, etc.); beach nourishment efforts; changes in natural sand supply due to the damming of river basins; or the presence of harbors that obstruct the movement of littoral sand. Figure 3-6 gives examples of different types of long-term beach changes for natural and nourished beaches. Long-term beach changes at Zuma Beach and in western Santa Monica Bay, located in the Zuma littoral cell, show natural fluctuations in beach width of 100 ft (30 m) or more, which have occurred over decadal and multi-decadal time scales that are correlated with Pacific Decadal Oscillation (PDO). Figure 3-7 compares the mean beach width at all beaches in the Zuma sub-littoral cell from 1928-2002 and the PDO index as presented by Orme et al. (2011).

While beach widths at Zuma Beach and in western Santa Monica Bay correlate reasonably well with shifts in water temperature, ocean wave characteristics, and the precipitation magnitude and frequency associated with PDO, many beaches did not show such a correlation. The time series that was considered in the study by Orme et al. (2011) consisted of over 77 years of data; however, it only considered 14 years of beach width data and covered 2 to 3 PDO cycles. Whether the beach width cycle's pattern would repeat again is questionable since coastal processes are complicated by many natural variables, such as large weather systems and human intervention. Also, the duration of PDO cycles can vary from 20 years to 40 years.

3.3 BEACH PROFILES

Several beach profile surveys have been carried out offshore of Broad Beach, extending from 1950 to 2012, with gaps where no survey data is available. These surveys were carried out by 1) USACOE between 1950 and 1970; 2) Fugro West, Inc., between 2002 and 2003; and 3) Coastal Frontiers (2012) from 2009 to 2012. Coastal Frontiers' beach profile surveys are presented in Appendix B.

Figures 3-8 and 3-9 show historic beach profile surveys carried out in 1951, 1962, and 1970 at transects (165+00) and (195+00). The locations of these two transects are indicated on Figure 3-8. These beach profiles show severe erosion in 1951 at the inshore and offshore part of the profile. In 1962, the beaches recovered slightly. Of particular interest is the beach profile of

1970, since it likely represents a beach profile for Broad Beach when the beach was wide. This beach profile had a berm height of 12 ft MLLW and a beach face slope of 1:6 (8.3°). Figures 3-8 and 3-9 show that the beach closure depth is about 27-30 ft. Closure depth is defined as the water depth when there is no significant change in the beach profile elevation along the coast. Broad Beach has a steep beach face slope, indicating that the sand grain size is coarse. This information, along with the beach profiles presented in Appendix B, provides a good basis for the design of a successful beach nourishment project at Broad Beach.

3.4 GRAIN SIZE ANALYSIS AT BROAD BEACH AND BORROW SITES

3.4.1 Broad Beach

Sand samples were taken at Broad Beach Transects 411 and 409 by M&N (2011). Figure 3-10 shows the locations of these transects. The results of the grain size analysis for the samples taken along these transects are presented in Table 3-1 and Figure 3-11. The mean grain size of the sand at the berm and beach face is about 0.30 mm (300 micron).

3.4.2 Borrow Sites for Beach Nourishment

Sediment core samples were taken at the Trancas Central and Dockweiler borrow sites; these samples were taken at several locations to dredging depth by vibracore equipment. The samples at each location were combined and analyzed for grain size distribution.

The locations of the core samples at the Central Trancas and Dockweiler borrow sites are shown on Figures 3-12 and 3-13. A comparison of grain size distributions at the Central Trancas borrow site and at Broad Beach is shown in Figure 3-14. Figure 3-15 shows a comparison between grain size distributions at the Dockweiler borrow site and at Broad Beach. The Central Trancas sand has a mean grain size (D50) that ranges from 0.12 - 015 mm, which is finer than the native Broad Beach sand. The Dockweiler borrow site sand is coarser than the Broad Beach sand with D50 ranges of 0.4 to 0.5 mm. Sand from the Ventura Harbor sand trap has a mean grain size of 0.2 mm.

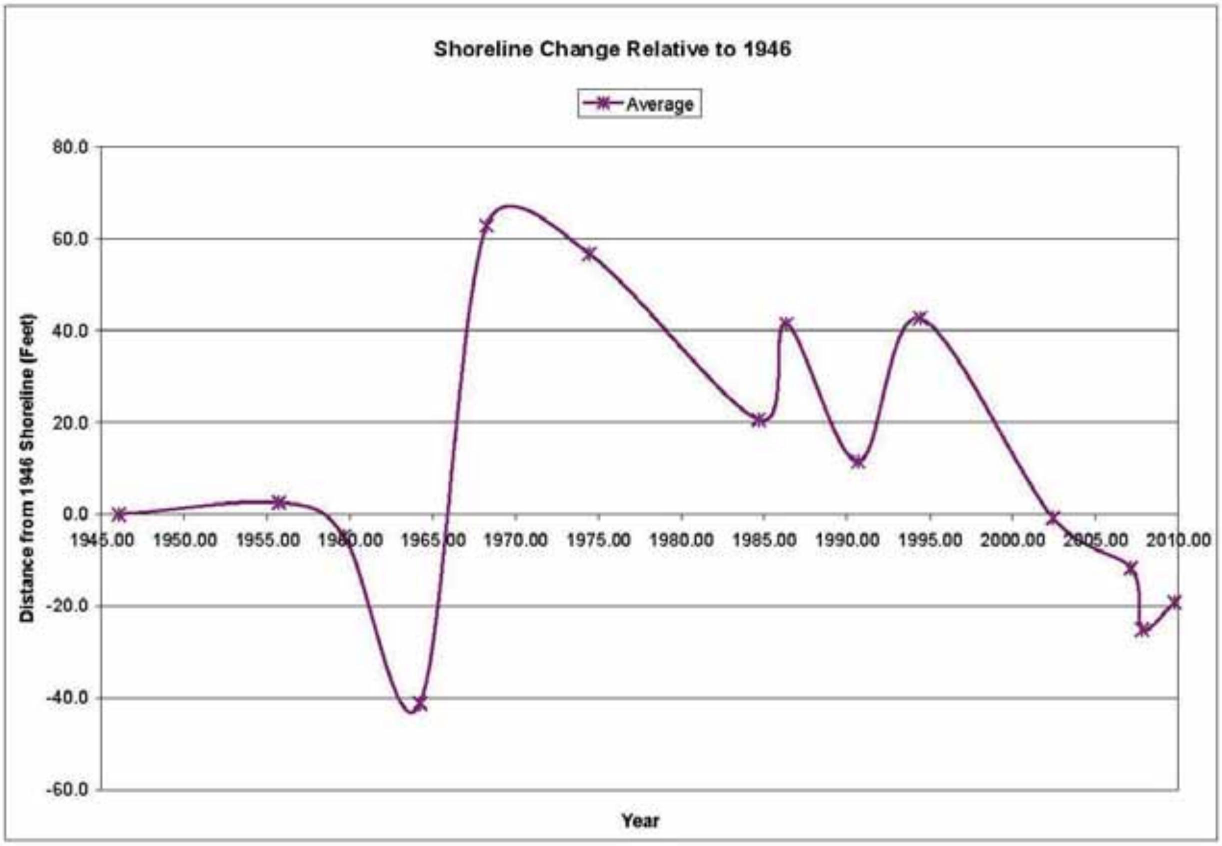

Figure 3-1. Average Broad Beach shoreline change relative to the 1946 shoreline.

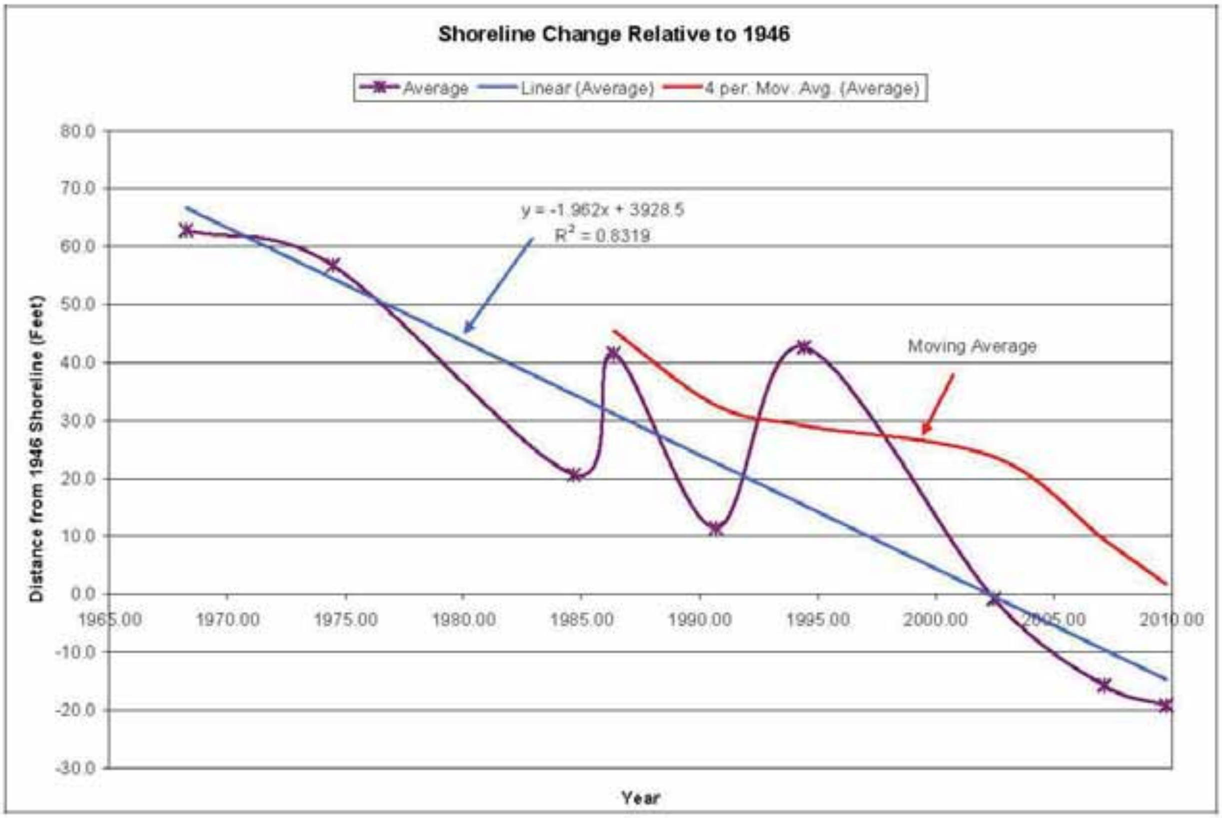

Figure 3-2. Broad Beach shoreline change and trends, 1970s-2010s.

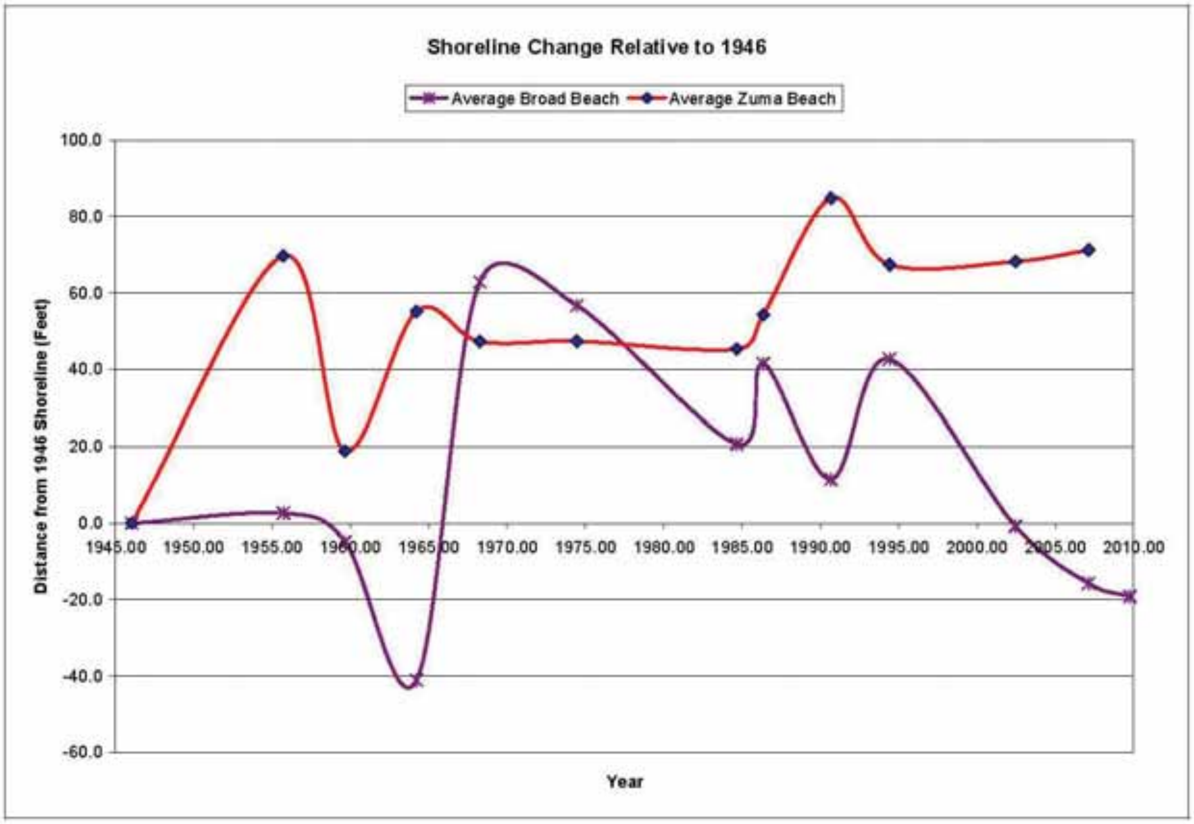

Figure 3-3. Broad Beach and Zuma Beach average shoreline positions.

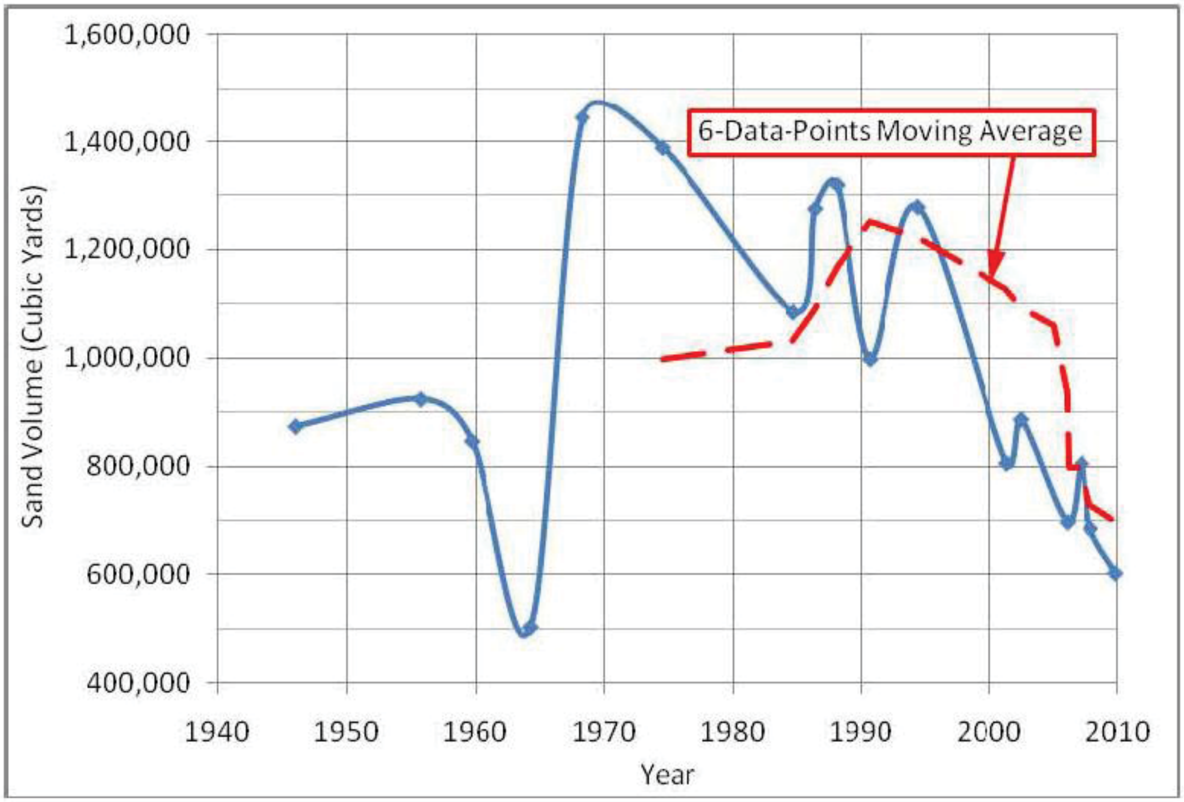

Figure 3-4. Volumetric changes, 1946-2009.

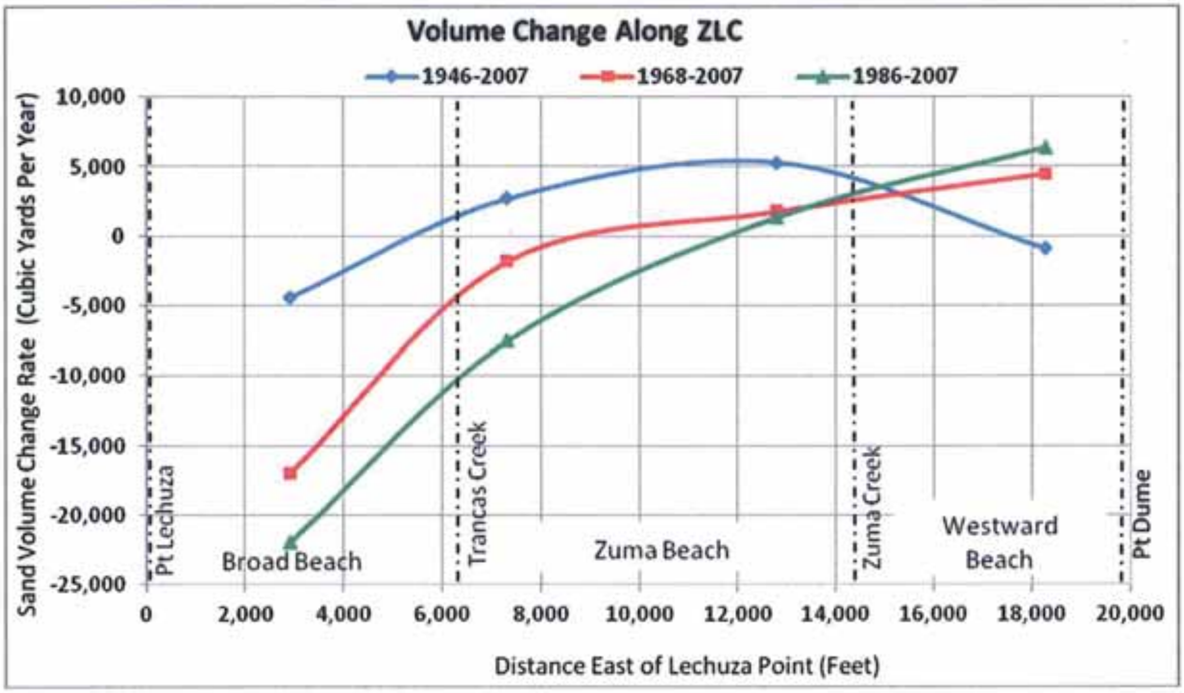

Figure 3-5. Alongshore distribution of volumetric change for different time intervals (1946-2007, 1968-2007, and 1986-2007).

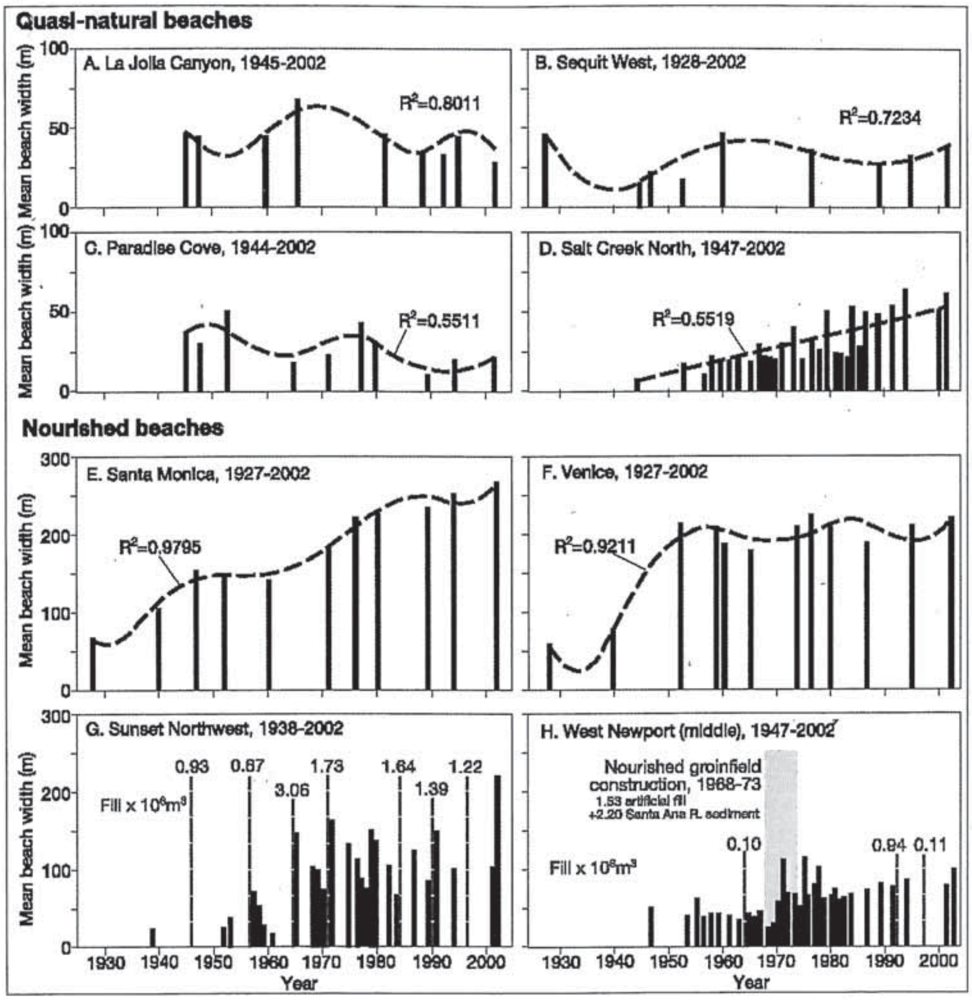

Figure 6. Examples of different types of beach change at natural and nourished beaches over study periods indicated; the vertical scale for beaches A-D is twice that of beaches E-H. La Jolla Canyon, Sequit West and Paradise Cove are natural beaches; originally natural, Salt Creek North shows incidental effect of inland development on beach width. Santa Monica, Venice and Sunset NW are frequently nourished beaches; middle West Newport shows effect of nourished groinfield construction, 1968-1973.

Figure 3-6. Long-term changes in beach width for selected beaches. From Orme et al. (2011).

Figure 7. Zuma cell, showing difference between mean beach width and time-series mean width for all beaches, 1928-2002 (modified from Zoulas and Orme 2007), compared with the Pacific Decadal Oscillation index, November-March, 1925-2005, with 10-year moving average (from Mantua 2007).

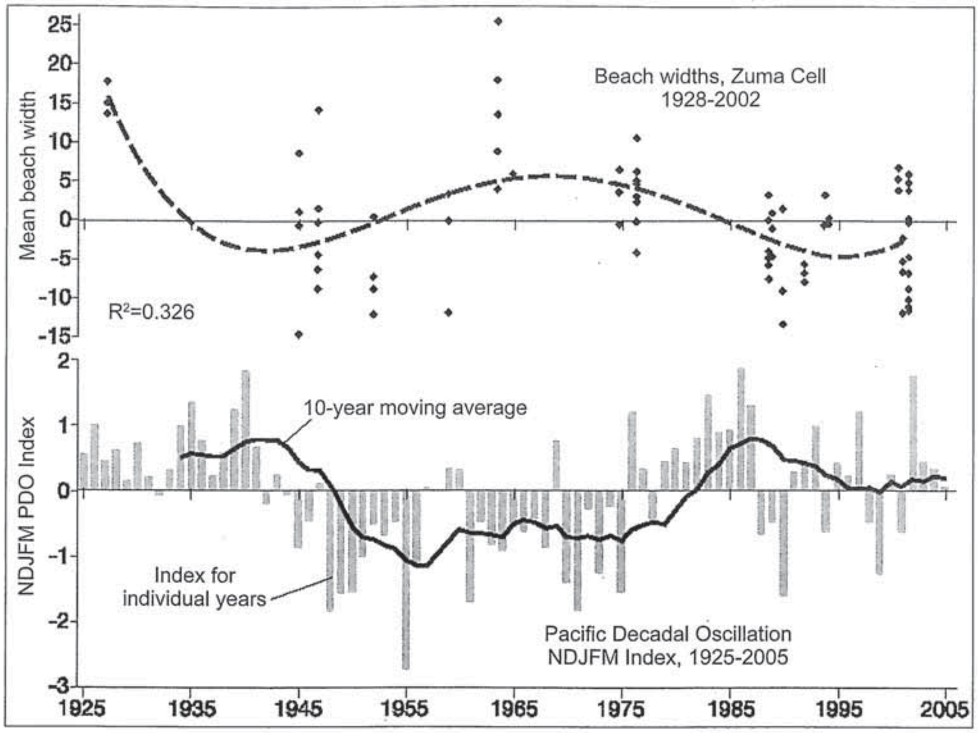

Figure 3-7. Comparison between mean beach width at Zuma Beach and Pacific Decadal Oscillation index. From Orme et al. (2011).

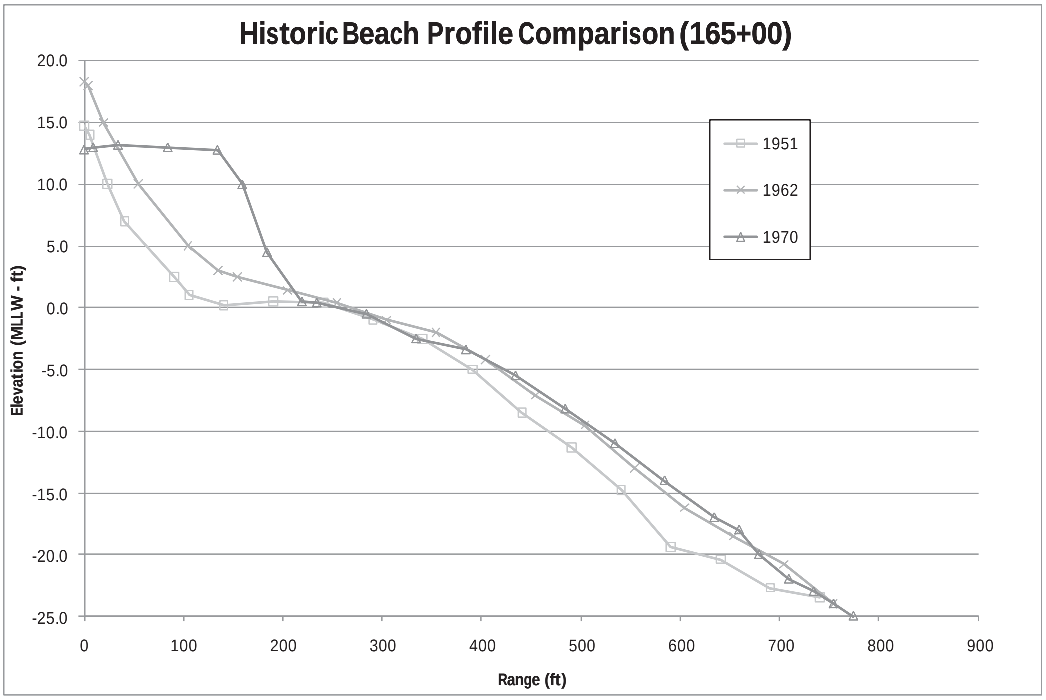

Figure 3-8. Historic beach profiles at Broad Beach (Station 165+00).

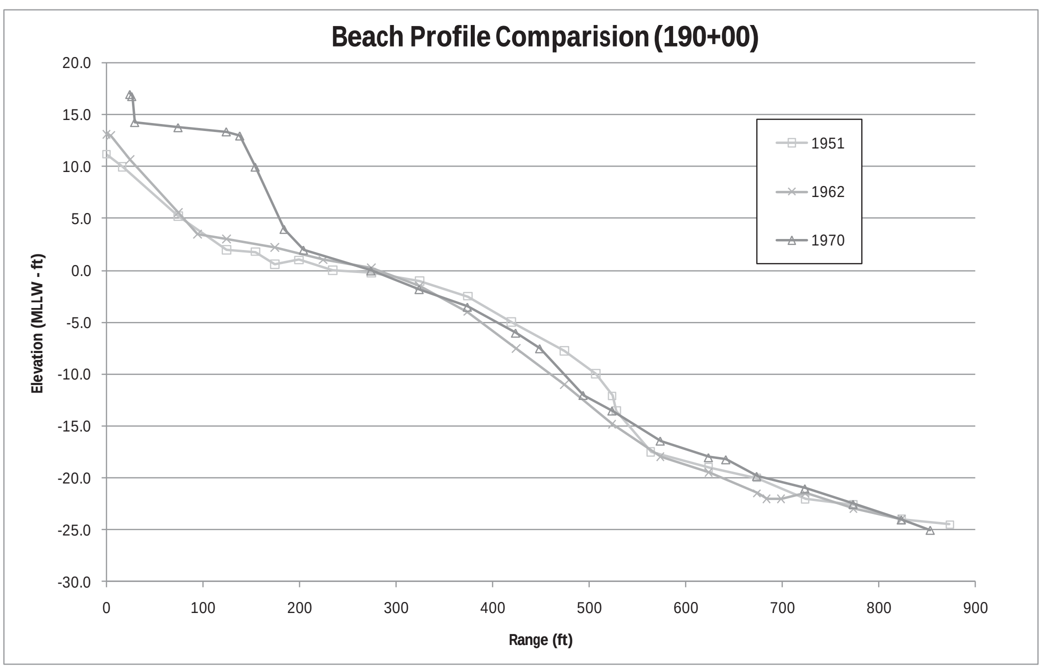

Figure 3-9. Historic beach profiles at Broad Beach (Station 190+00).

Figure 3-10. Beach profile transect locations. From M&N (2011).

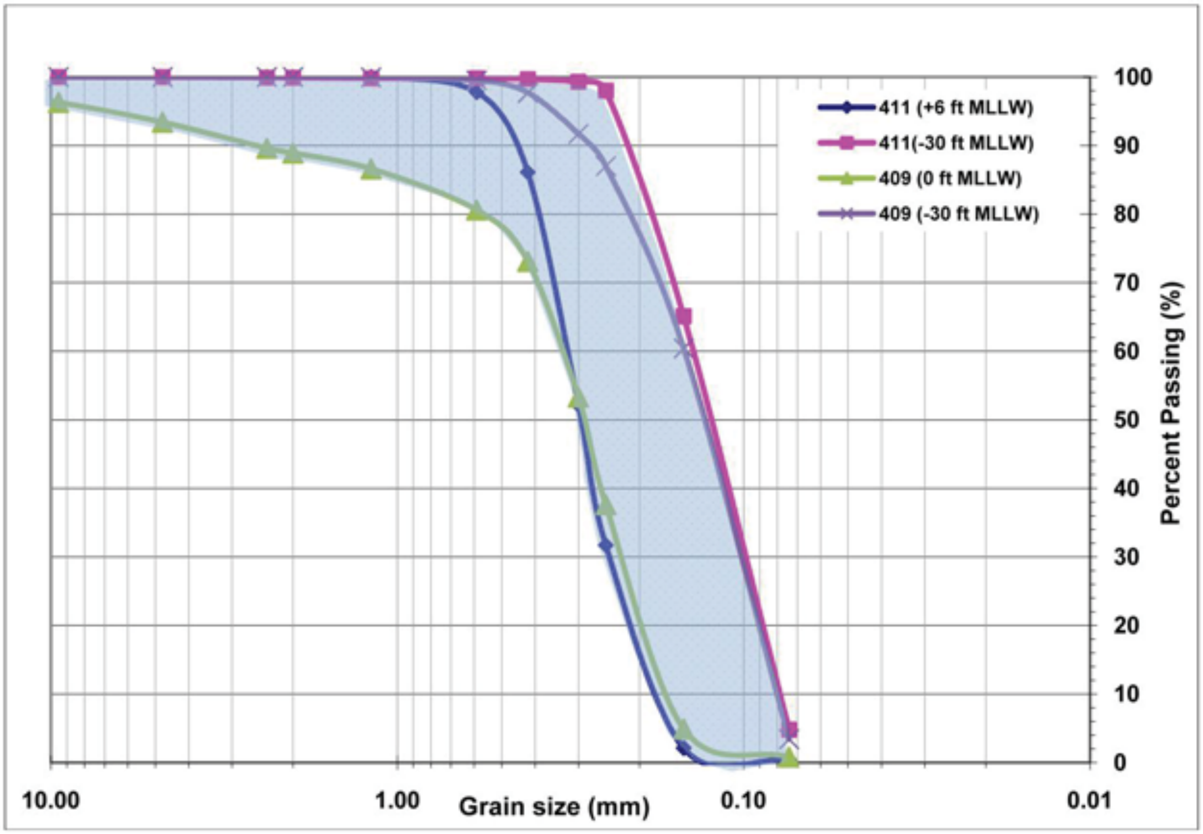

Figure 3-11. Composite grain size envelope for Broad Beach. From M&N (2011).

Table 3-1. Grain size results summary from Transects 409 and 411.

Transect	Analysis Type	+6 ft	0 ft	-6 ft	-12 ft	-18 ft	-24 ft	-30 ft	Mean
411	% fines[a]	0.40	0.80	1.00	2.60	3.40	3.60	4.80	**2.37**
	D50[b]	0.295	0.416	0.320	0.262	0.147	0.143	0.130	**0.24**
409	% fines[a]	1.10	0.80	2.20	1.50	1.90	2.40	3.40	**1.90**
	D50[b]	0.269	0.289	0.147	0.171	0.168	0.139	0.135	**0.19**

[a] Passing #200 sieve.
[b] D50 is the mean value of the sand sample.

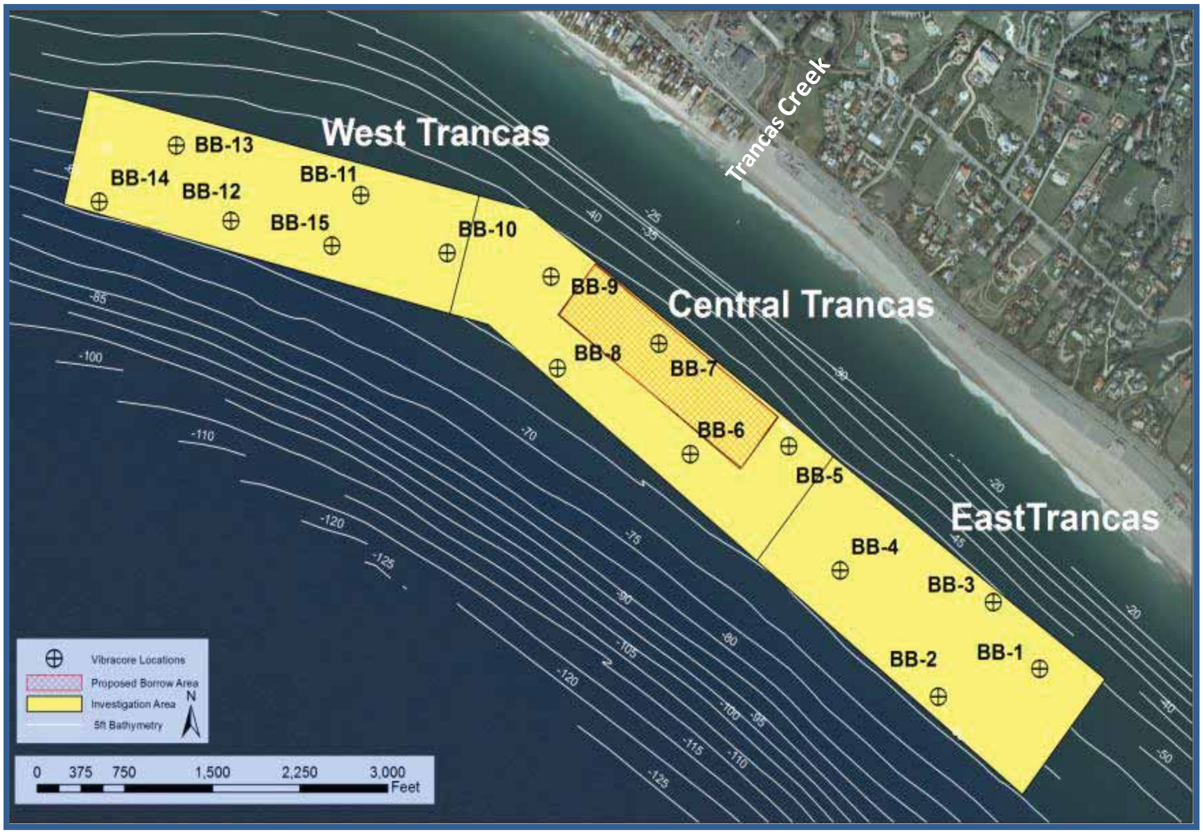

Figure 3-12. Location of grain size samples at Central Trancas borrow site.

Figure 3-13. Location of grain size samples at Dockweiler borrow site.

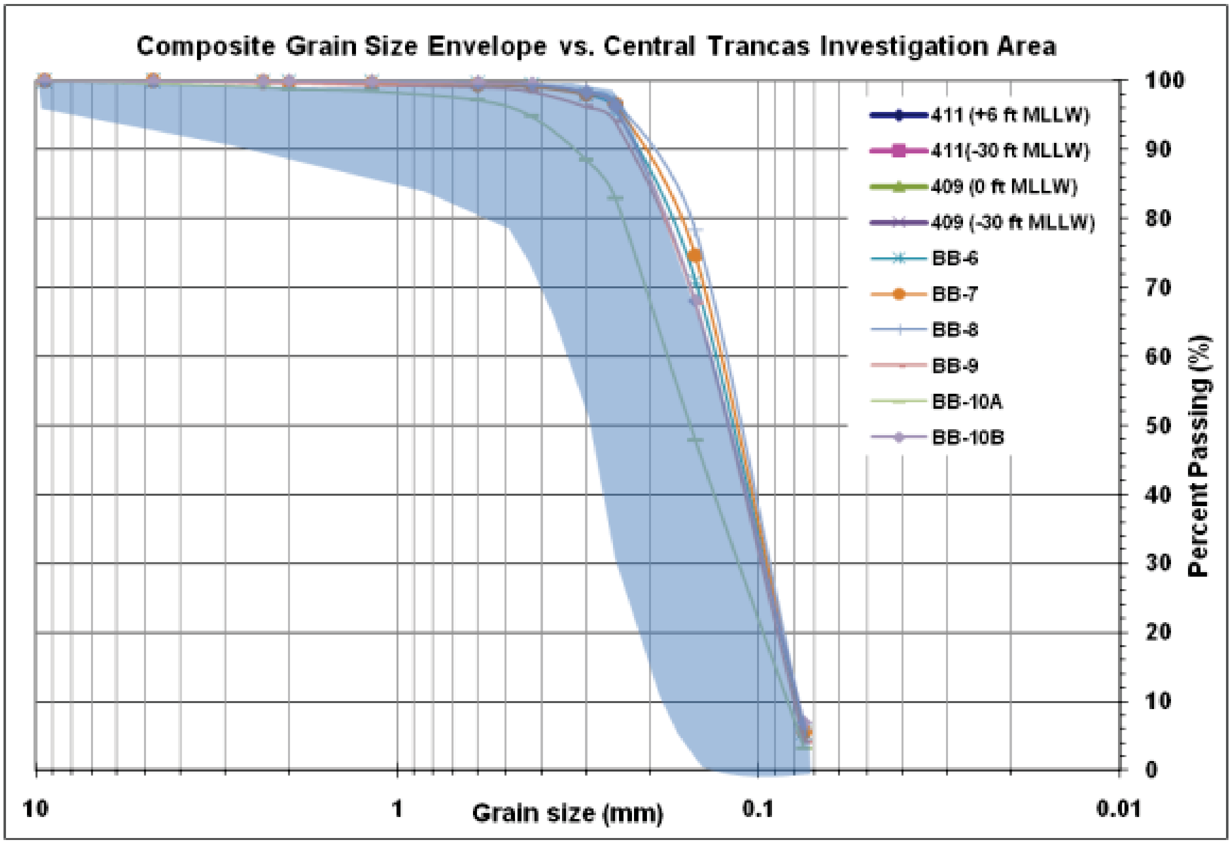

Figure 3-14. Grain size distribution of sand at Central Trancas borrow site and Broad Beach.

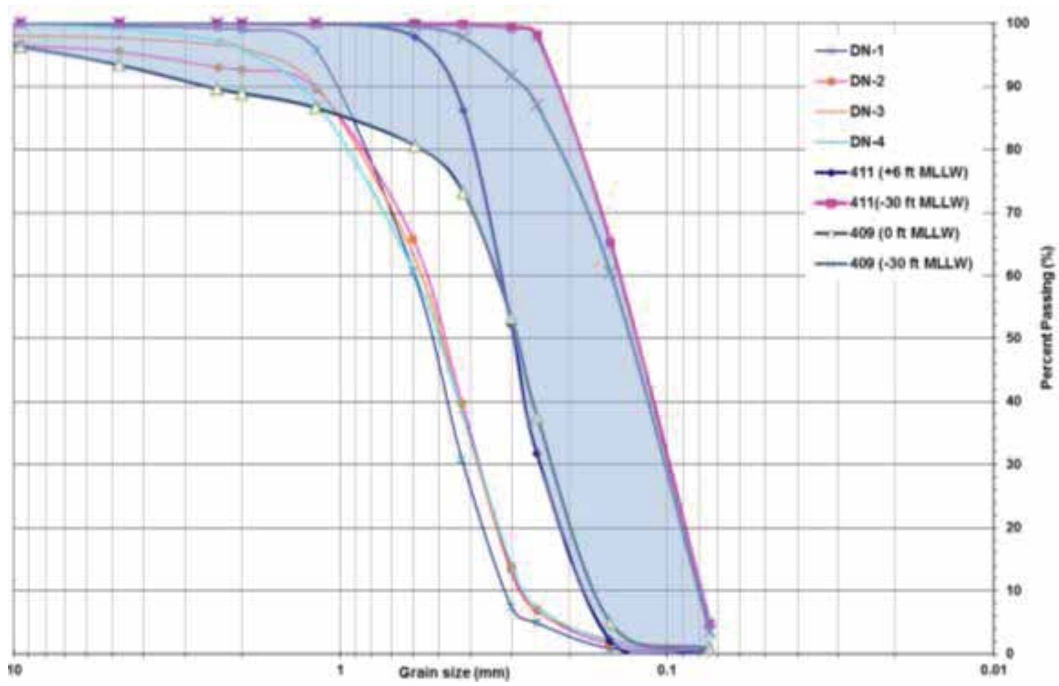

Figure 3-15. Grain size distribution of sand at Dockweiler borrow site north and Broad Beach.

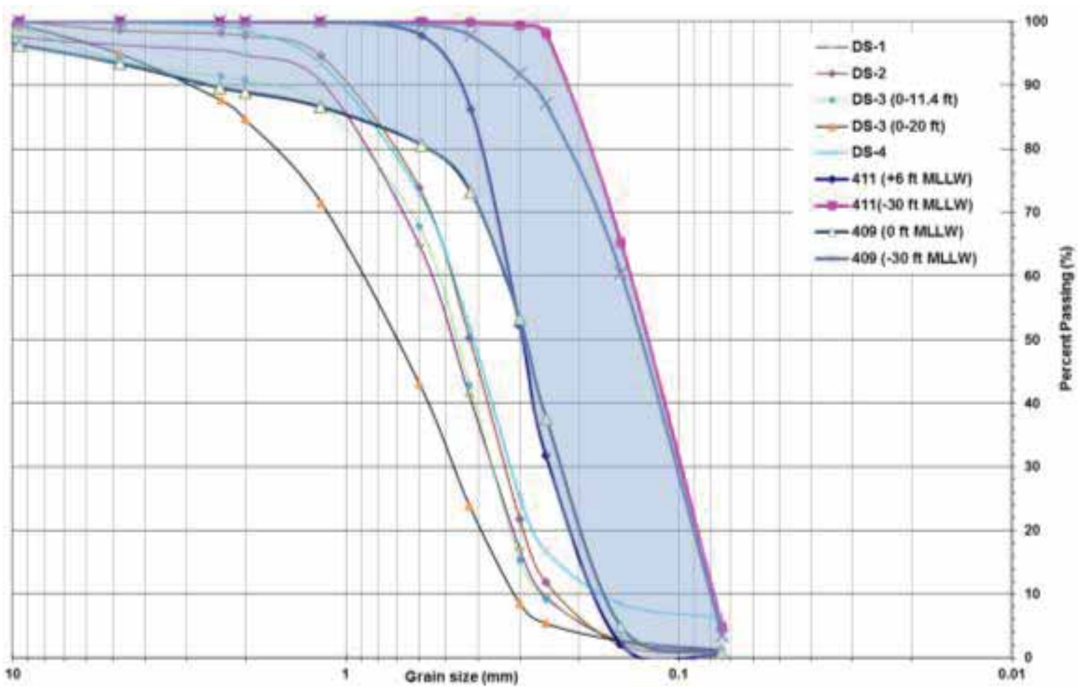

Figure 3-16. Grain size distribution of sand at Dockweiler borrow site south and Broad Beach.

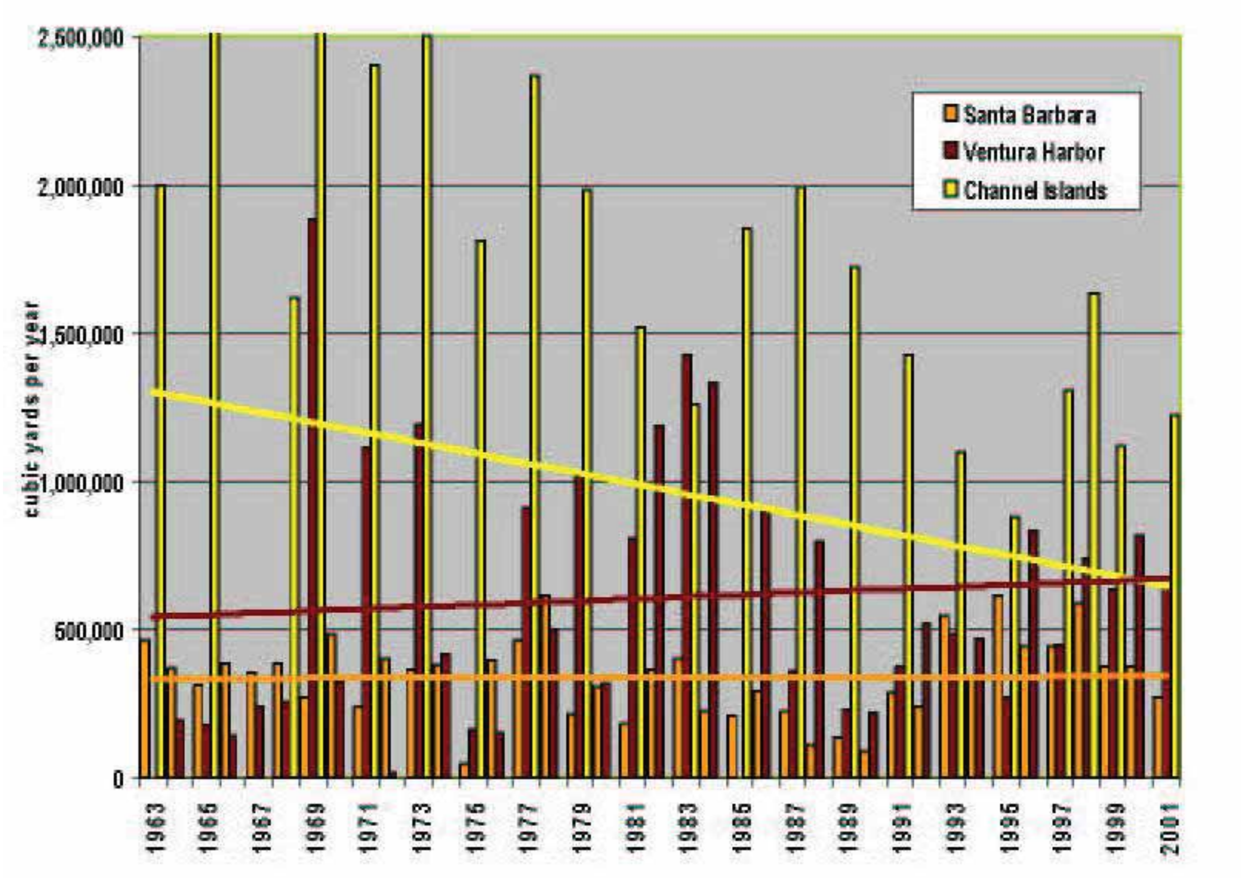

Figure 3-17. Long-term dredging history for the Santa Barbara, Ventura, and Channel Islands harbors. From Griggs and Patsch (2002).

4.0 LONGSHORE TRANSPORT AT BROAD BEACH

Estimates of longshore sand transport were made by M&N (2010, 2012a,b) utilizing empirical equations. They estimated the gross longshore sand transport between 1946 and 1974 to be 792,000 cyy, while between 1974 and 2007, it was 544,000 cyy. The net longshore transport between 1946 and 1974 was 424,000 cyy, while between 1974 and 2007, it was 280,000 cyy.

M&N concluded that the change in the yearly longshore sand transport from the earlier period to the later one was the result of a change in wave conditions. These changes also led to noticeable erosion at Broad Beach between 1974 and 2007.

The predominant longshore and cross-shore sand transport at Broad Beach is to the east and onshore respectively, except during large storms. The figures by O'Reilly and Flick (2008) in Appendix A show that waves from the west and southwest windows (during the winter season) that are larger than 5 feet (1.5 m) transport sand eastward and offshore, and these waves are responsible for transporting most of the sand from Broad Beach to the east, but such waves do not occur very often. This pattern was noticeable between 2000 and 2008.

M&N (2012a), in coordination with Everts Coastal, used the wave data simulated by O'Reilly and Flick (2008) between 2000 through 2008 and calculated for every year the longshore transport downcoast (east) and upcoast (west) and the net and gross longshore sand transport at about 1,000 ft east of Lechuza Point. The results are presented in Table 4-1.

Table 4-1. Longshore transport at about 1,000 feet east of Lechuza Point.

Year	Q Downcoast	Q Upcoast	Q Net	Q Gross
2000	120,534.9	-53,338.5	67,196.44	173,873.4
2001	181,485.2	-64,373.6	117,111.5	245,858.8
2002	170,395.7	-30,560.8	139,834.9	200,956.5
2003	174,458.2	-34,034.4	140,423.8	208,492.6
2004	128,022	-47,249.2	80,772.82	175,271.3
2005	150,521.3	-53,792	96,729.32	204,313.3
2006	175,093.7	-43,736.6	131,357.1	218,830.2
2007	190,272.3	-29,410.5	160,861.8	219,682.7
2008	164,553.3	-58,993.4	105,559.8	223,546.7
Average	161,704.1	-46,165.4	115,538.6	207,869.5

5.0 LONGEVITY OF NOURISHMENT SAND AT BROAD BEACH

5.1 THEORETICAL APPROACHES

Moffatt & Nichol (2011) have presented five theoretical methods for estimating the longevity of beach nourishment sand on Broad Beach. These methods are described in Appendix C, which was taken verbatim from M&N (2010). These methods are:

1. Method 1: Shoreline Rotation Within a Hook-Shaped Bay
2. Method 2: Netherlands Method
3. Method 3: Project Downcoast of a Complete Littoral Barrier (Modified Equation)
4. Method 4: Project Downcoast of a Complete Littoral Barrier (Curve Fit)
5. Method 5: Worst-Case, Rectangular Fill Deposit with Spreading at Both Ends

The results of these five methods are presented in Figure 5-1. Method 1 is referred to as the "disequilibrium approach" and is based on the premise that Broad Beach will act as a Hook-Shaped Bay (Everts and Eldon, 2002). Whether Method 1 assumes that a shift in the approach direction of incident waves caused the recent observed loss of sand at Broad Beach, or that reduced sand supply to Broad Beach caused the loss of beach width between the 1970s and the present, the results for sand longevity are similar.

Method 2 is based on an approach developed by Verhagen (1992), which assumes that the beach will erode at the same rate as it did before the project, plus an additional amount to account for spreading losses and loss of fines. The supposition is that the effect of an artificially-introduced disequilibrium in the planform will increase the previous sand loss rate by 40 percent. The accuracy, of course, is only as good as the historic survey data and the assumption that the past is a quantitative key to the future.

Method 3 is based on a theoretical approach developed by Campbell et al. (1988), which assumes that Lechuza Point is a barrier for littoral drift (no sand input from the west to Broad Beach). In the presented results, M&N assume that the net longshore sand transport at Lechuza Point (west boundary of Broad Beach) is equal to the natural net transport (225,000 cyd), and that the sand bypassing Broad Beach is 225,000 cyd minus 32,000 cyd, where 32,000 cyd is the volume of sand loss from Broad Beach during 2007. The longevity estimate for the nourished sand on Broad Beach was derived from the modification of a deterministic equation presented by Campbell et al. (1988).

Method 4 is based on the same approach outlined in Method 3, but instead of using the modified equation, an approximate fitting curve presented by Campbell et al. (1988) was used to calculate the longevity of the nourished sand along Broad Beach.

Method 5 is based on studies by Work and Dean (1995) and Dean (1996), who presented a deterministic approach to predicting fill loss where the beach is long and straight and the fill is rectangular with no tapering at the ends. The results indicate that the sand will last 5 to 6 years. Work and Dean’s approach may be not applicable because the fill is unlikely to spread westward around Lechuza Point.

5.2 NUMERICAL MODELING

M&N (2012a,b) presented a study to simulate changes in the shoreline resulting from placing 600,000 cyd of sand at Broad Beach to create a wide sandy beach backed by a system of sand dunes using the GENESIS (USACOE, 1989) numerical model. This model is regularly updated by the U.S. Army Engineers Research and Development Center (ERDC). M&N recognized that the accuracy of numerical modeling for the shoreline is limited because of the complexity of coastal processes. However, the GENESIS program has been utilized in many artificial beach nourishment projects and has provided some useful results. Its limitations are discussed below.

GENESIS is a one-line model that accounts only for longshore sand transport. However, sand moves along the coast by waves alongshore (parallel to the shoreline) and also across-shore (perpendicular to the shoreline). This model’s results depend to a large extent on the input data for the program, including: 1) wave data (height, period, and direction), 2) bathymetry data for the study area, and 3) the shoreline orientation, as well as 4) selecting the proper values for the program parameters. Longshore sand transport equations are sensitive to breaking wave angles and shoreline orientations, such that small errors in estimating these angles can result in inaccurate results.

M&N (2012) has carried out several attempts to calibrate and validate the numerical model, and they have found that: 1) the model can predict the shoreline reasonably well for Broad Beach, but not at the area downcoast of it; 2) the model results should not be used to define a specific shoreline position at a specific date; and 3) the purpose of the model is to predict general long-term shoreline trends. Figure 5-2 presents the GENESIS shoreline changes after beach nourishment for a period of 10 years. The rate of beach loss is greatest at the west end of Broad Beach and indicates that the nourished beach may last only 3-4 years near Lechuza Point. The model results suggest that beach nourishment may last up to 7 or 8 years at the east end of Broad Beach.

From Figure 5-2, M&N (2012) concluded that beach width at the west end of Broad Beach would be less than 50 feet two years after the initial nourishment. At this stage, they recommend moving the sand annually from the east end of Broad Beach to the west end (backpassing) to widen the western portion. Figures 5-3 and 5-4 show the shoreline changes resulting from the backpassing of sand from the east to the west on Broad Beach after two and four years, respectively. The model results suggest that backpassing the sand to the west of Broad Beach will increase beach width at the west end, and will likely prolong the residence time of the beach nourishment in general. The backpassing of nourished sand from one location to another has been carried out in the past at several locations. A photograph of a backpassing operation at Long Beach is presented in Figure 5-5.

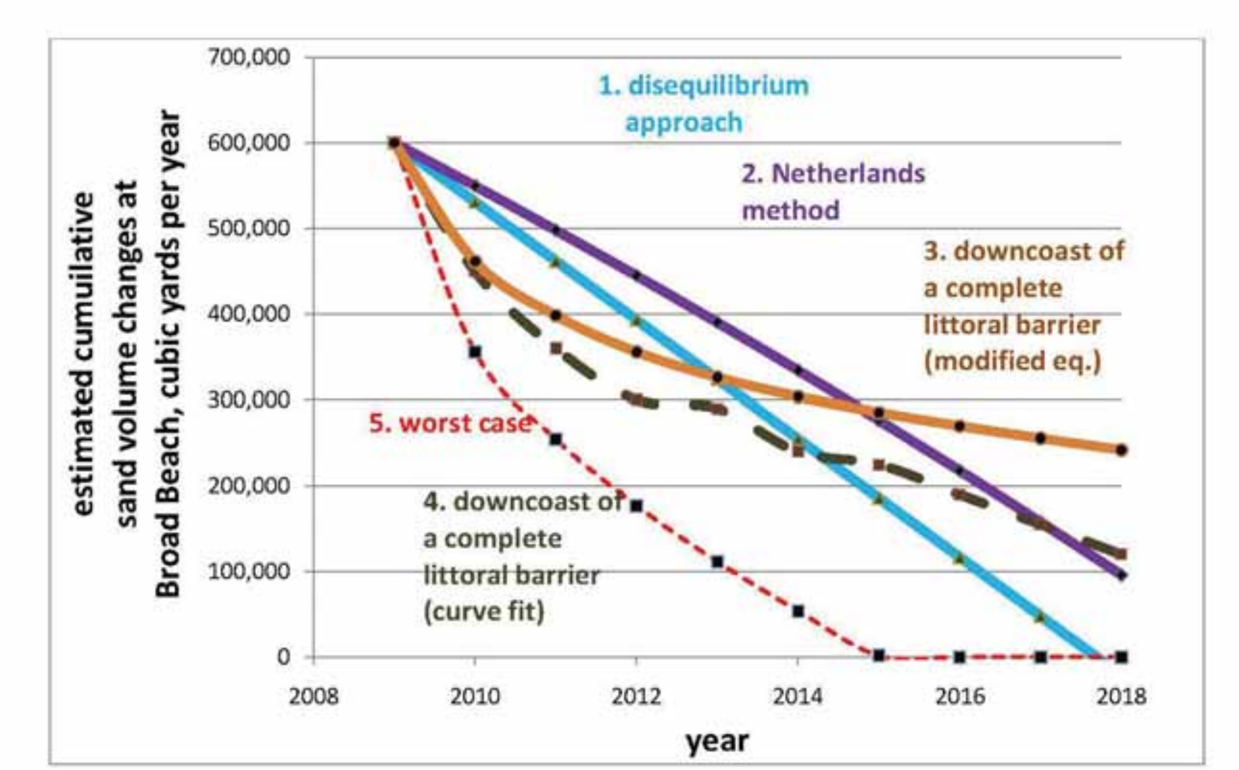

Figure 5-1. Estimates of sand loss at Broad Beach if 600,000 cubic yards of beach fill had been placed in 2009 to expand the beach an average of 70 feet after the profile had equilibrated.

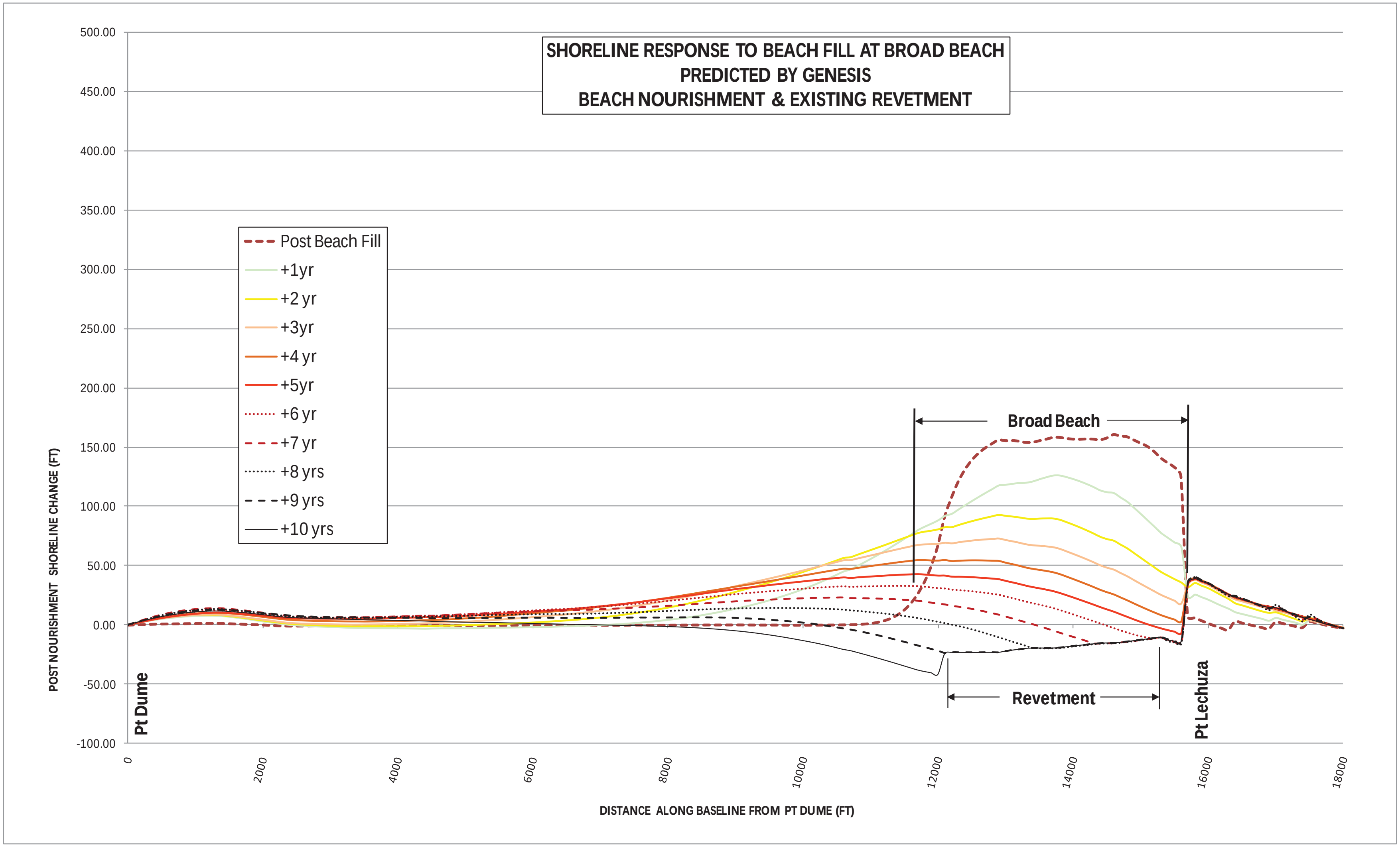

Figure 5-2. GENESIS results, beach nourishment with existing revetment.

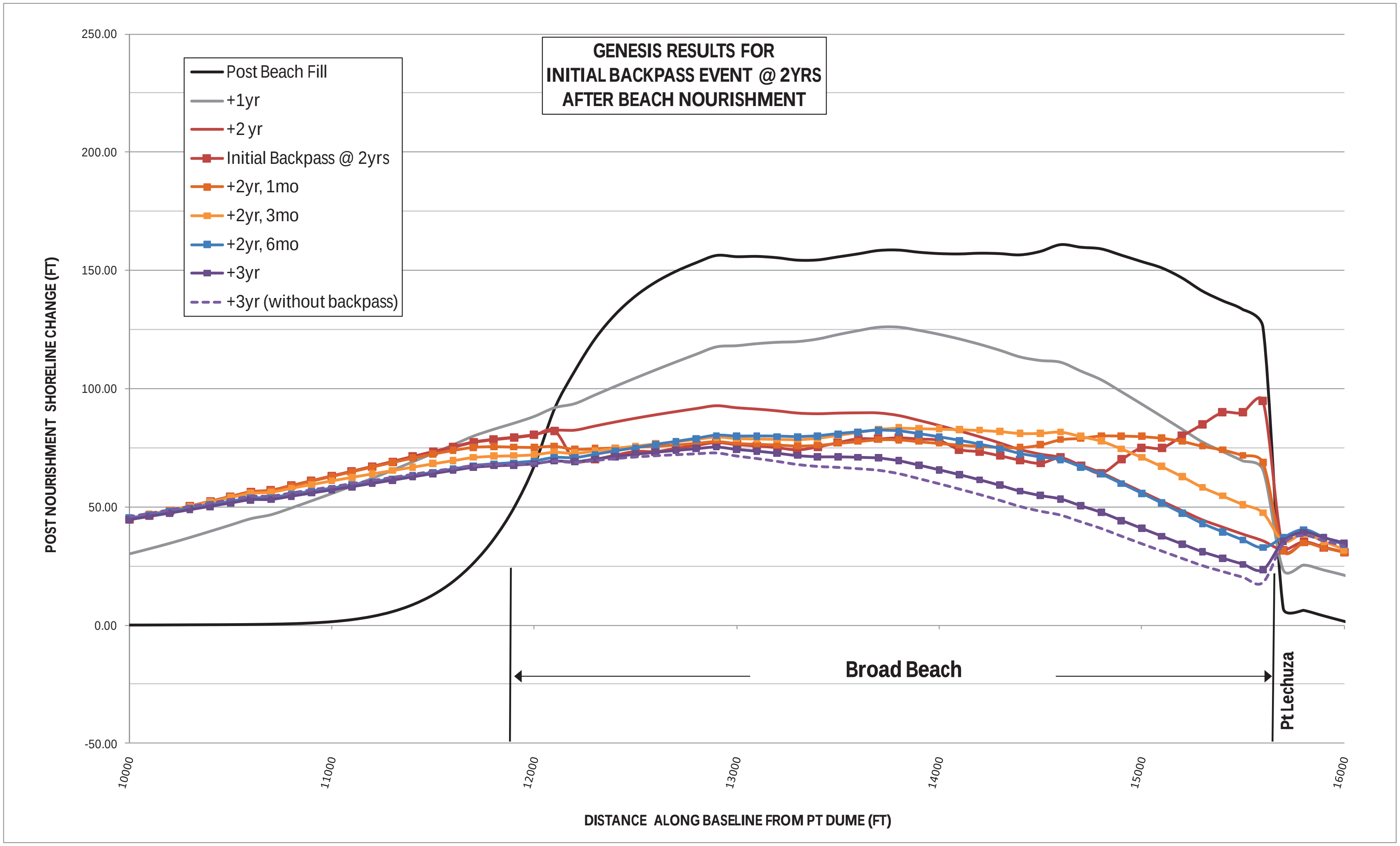

Figure 5-3. GENESIS results, initial backpass two years after beach nourishment.

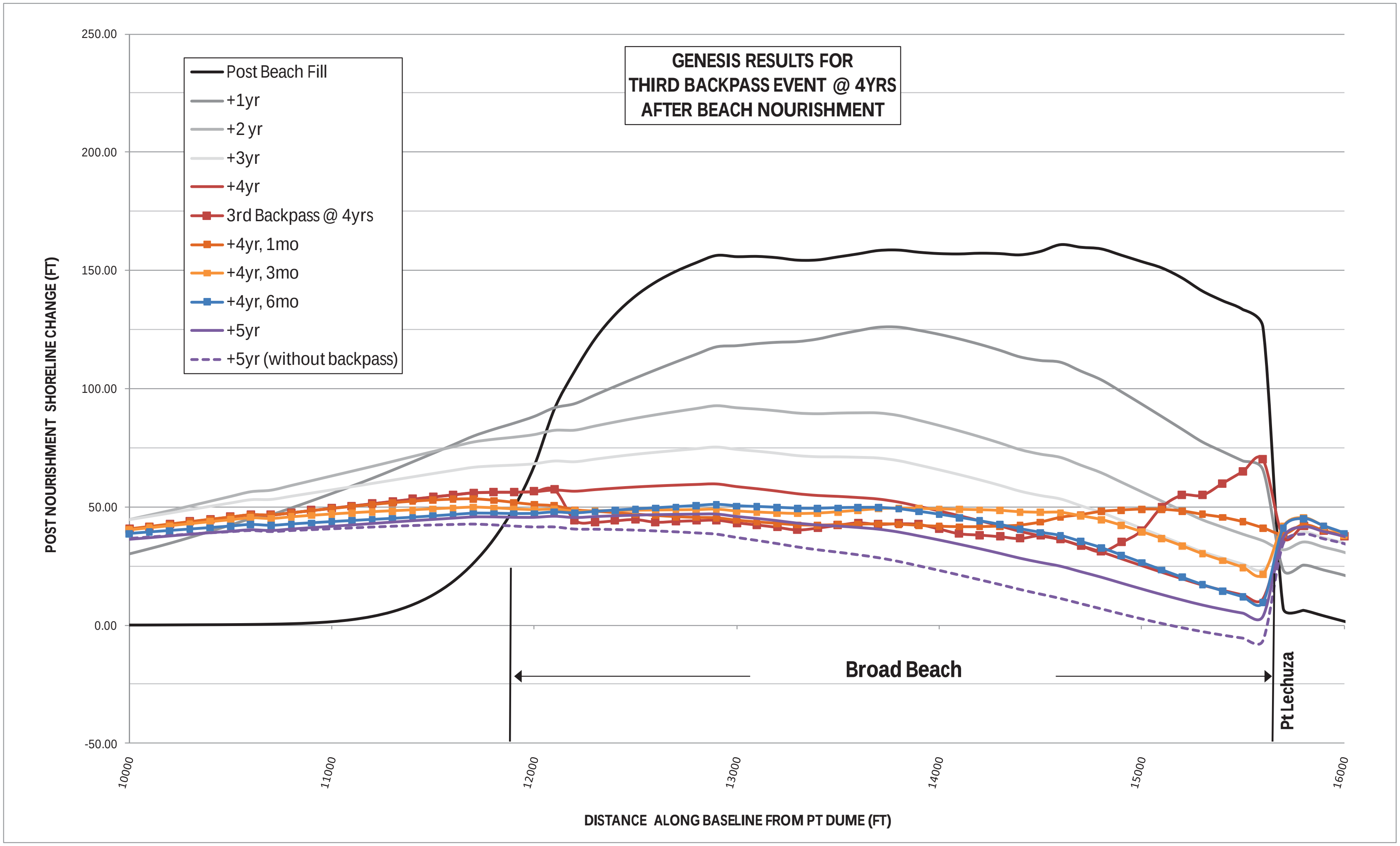

Figure 5-4. GENESIS results, third backpass four years after beach nourishment.

Figure 5-5. Backpassing operation in Long Beach, CA.

6.0 REVETMENT STABILITY

This section describes the stability of the revetment in response to waves and wave run-up. The structural integrity of the revetment is important for the long-term protection of the homes along Broad Beach, as well as for the ocean waters. The latter could be impacted by contamination from septic effluent and other debris from beachfront homes if the revetment should fail. If that were to happen, both homes and septic systems could be damaged or destroyed, causing an imminent public health risk.

6.1 DESCRIPTION OF EXISTING REVETMENT

The existing revetment is 4,100 feet long, extending from 30760 Broad Beach Road, approximately 600 feet west of Trancas Creek, to 31340 Broad Beach Road, just west of the western public access point for Broad Beach. A total of approximately 36,000 tons of rock was used to create the revetment in early 2010. The revetment is 27 to 41 feet wide at its base and 13 to 17 feet in height, with the overall height averaging around 15 feet. Individual boulders for the majority of the revetment weigh between ½ and 2 tons, although many smaller rocks were used during construction. The portion of the revetment between 31316 and 31340 Broad Beach Road (a distance of approximately 400 ft) was designed to be more robust by Terra Costa Consulting Group, Inc. (2008); it incorporated larger rocks that weighed between 3 and 4 tons each (Figure 6-1). The remainder of the revetment (3,700 ft) was designed by M&N (2012a,b). Figure 6-2 shows cross-sections of the existing revetment.

The boulders of the existing revetment were placed on top of a filter fabric to support them and help resist vertical settlement of the rock into the beach sand. The stability of the existing revetment is, therefore, dependent on the stability of the sand layer underlying the boulders of the revetment. The source quarry (or quarries) for the boulders is/are not known.

6.2 REVETMENT STONE SIZE

The stability of the existing revetment's armor stone was evaluated using the Hudson formula outlined in Moffatt & Nichol (2012). The existing revetment (except for the 400-ft-long western portion) was constructed with two layers of armor stone using rock sizes ranging between ½ and 2 tons. Based on a specified gradation, the median armor stone is between 1 and 2 tons of rough quarry stone, randomly placed. For a wave height of 6 feet at the toe of the revetment, the rock size according to Hudson's equation (USACOE, 1984) is 1-ton stone, while for a wave height of 8 feet, the rock size is 2-ton stone. Wave heights greater than 6 to 8 feet breaking in front of the existing revetment will likely result in a higher percentage of damage or displacement of the armor stone. The design wave heights calculated for the critical design condition of extreme tide, scour, and sealevel rise (SLR) range from 8.9 feet to 9.6 feet. For comparison, the armor stone sizes, which were used for the western part of the revetment (400 ft in length), varied between 3 and 4 tons in weight. These results indicate that the western portion of the existing revetment can withstand these design wave heights with minimal damage. Armor stone for the remainder of the existing revetment (3,700 ft in length) is under-sized, and damage can be expected with large storm waves.

6.3 JUNE 13, 2012 FIELD INSPECTION OBSERVATIONS

Field inspection by AMEC's geotechnical engineers has substantiated many of the above-mentioned design assumptions and in-place rock revetment conditions. As reported, the western end of the revetment consists of larger stones than the eastern end; the team noted a distinctive change in rock size that occurs at about 31346 Broad Beach Road (i.e., the westernmost beach access point). Thus, the larger stone exists along the western 490 feet (13 percent of the length), and the smaller stone exists along the eastern 3,700 feet (87 percent of the length). The use of smaller stone, which was reportedly placed on the interior, was unable to be observed because only the exterior could be seen.

Overall, the exterior stone appeared to be stable with little evidence of movement having occurred during the two-year performance period (2010–2012). On the eastern end where the smaller rock exists, the field survey team noted a few examples where individual rock pieces had been separated from the wall and now existed on the beach in front of the wall (seaward side). In these local cases, the in-place of the wall appeared stable with no obvious perturbations in the overall linear shape. In these areas, the geotechnical field team did not note any deflections in the top of the wall that could indicate overall wall settlement. At the western end where the larger rocks exist, the field survey team did not note any pieces that had been detached from the rock mass. It appears that the rock sizing indicates the relative stability of the rock mass, but a few examples of detached stones suggest that use of a larger size would be warranted.

The rock revetment was designed as a trapezoid that is 13 to 17 feet high and about 27 to 41 feet high at the base. Without an "As-Built" survey to confirm placed conditions, the team's reconnaissance relied on multiple visual sitings along the top of the wall, which indicated that the wall is approximately level and without significant variations in elevation.

Damage to the revetment from an extreme event of this type does not suggest a complete failure of the revetment. The flexible nature of a stone revetment is one reason that it is the most commonly used shore protection device. This flexibility can accommodate minor settling and even displacement of some stones without complete loss of protection. Damage from waves exceeding the design wave is usually progressive and can be repaired provided there is sufficient time between consecutive storm events. Although the existing revetment lacks the safety factor of a typical coastal revetment, the structure has performed well under direct exposure over the past several years and will continue to provide a reliable last line of defense over the design life of the Project.

6.4 WAVE RUN-UP

Wave run-up is defined as the rush of water up a beach or coastal structure caused by or associated with wave-breaking. The run-up elevation is the maximum vertical height above 0 ft, MLLW that the run-up will reach. If the run-up elevation is higher than the beach berm, the excess represents overtopping. Run-up depends on the incident wave characteristics, the slope and porosity of the beach, and if a structure is present, that structure's shape, slope roughness, permeability, and water depth at the toe.

M&N (2012a,b) estimated the run-up and overtopping for the existing conditions at Broad Beach for a 25-year return wave period. They considered two cases: 1) wave height equal to 9 ft and wave period equal to 16 seconds; and 2) wave height equal to 9 ft and period equal to 20 seconds. They estimated wave run-up to be 22.7 and 24.7 ft MLLW, respectively. Since there is no beach in the existing condition, waves break at the toe of the revetment. For worst-case design deep-water wave height, Terra Costa Consulting Group, Inc. estimated wave run-up of about 30 ft above mean sea level, assuming a 15 ft wave height with a 12-second period.

After the beach fill, wave run-up values will be less than those values presented by M&N for the same wave conditions, because: 1) waves will break farther away from the shoreline; and 2) as the broken wave propagates along the beach slope, waves will lose a considerable amount of energy.

In the absence of a wide beach fronting the existing revetment, waves would likely overtop the revetment frequently since the height of the existing emergency revetment is low. Overtopping of the revetment is likely to increase the probability of damage to the revetment by return water and erosion of the sand underneath it. Further, some of the homes' leach fields are located just at the back of the revetment, which will impact the returned water quality and impose an increase in bacterial concentration nearby and offshore of the homes during wave storms. It is recommended that the height of the revetment be at least 20 ft. The run-up studies being conducted by home owners' consultants are not sufficient to determine the percent of time that the revetment would be overtopped, either before or after the fill project.

Damages to the homes due to wave overtopping would be possible with the presence of the existing revetment in the absence of a wide beach, especially if there were also damages to the home's foundation or supporting structures or to the revetment. Inundations of the properties would be expected during large wave storms.

Figure 6-1. The western part of the existing revetment designed by Terra Costa Consulting Group, Inc. (2008).

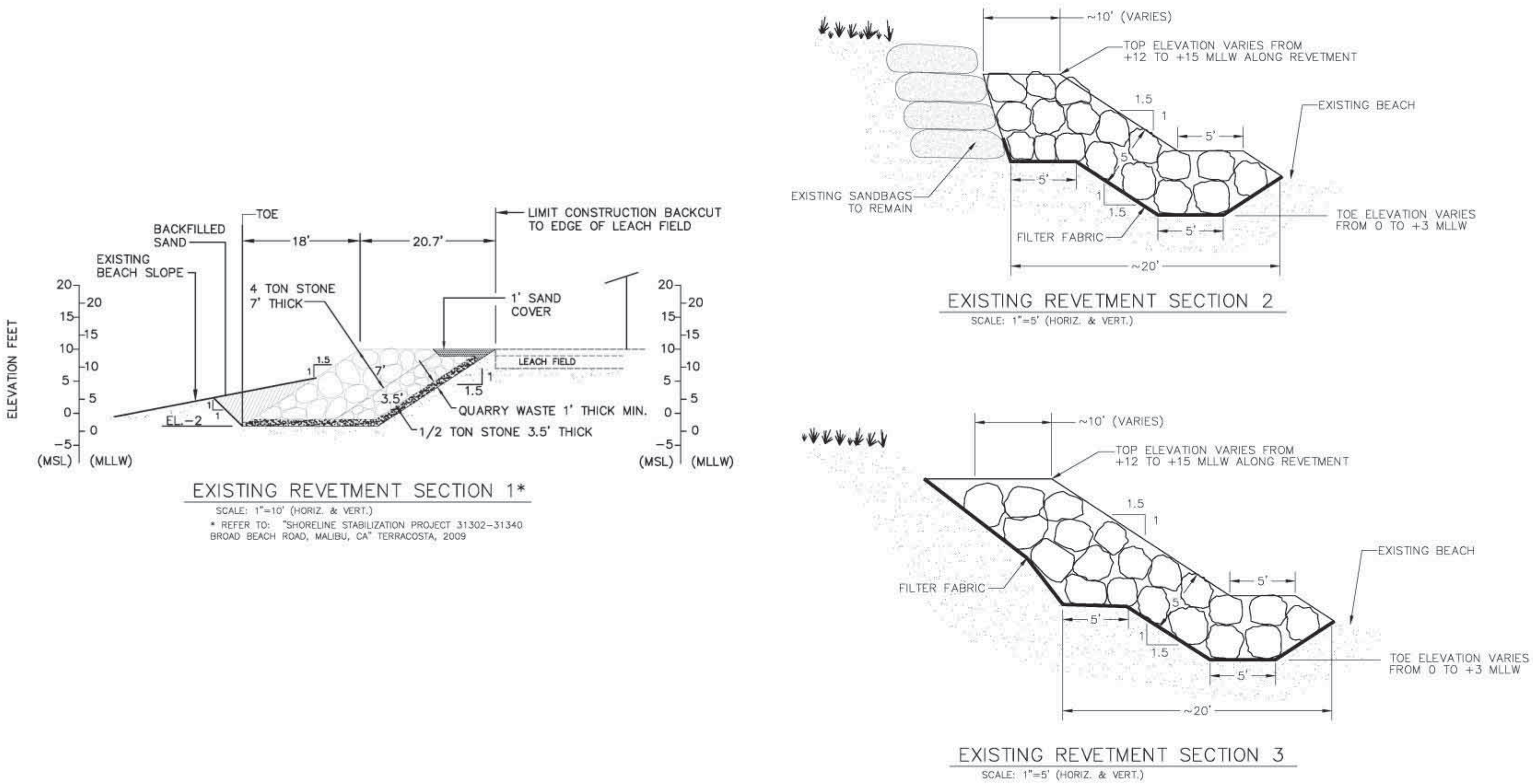

Figure 6-2. Existing revetment cross-sections. The cross-section for the 400-foot-long western portion of the revetment is on the left, and the other revetment cross-sections are shown on the right, both with and without sandbags.

7.0 PHOTOGRAPHS

Appendix D contains selected aerial photographs of Broad Beach (located between Lechuza Point and the mouth of Trancas Creek) taken from 1946 through 2011, which illustrate the history of the beach width (shoreline).

Photos D-5, D-6, D-10, D-11, and D-13 through D-27 are from the California Coastal Records Project (CCRP, 2009) and are copyrighted. Permission is required from CCRP (www.californiacoastline.org) prior to publishing or distributing these photographs.

8.0 CONCLUSIONS

Broad Beach was wide during the late 1960s and 1970s, and it remained so into the 1980s, when residential development was still ongoing. Most of the properties were built between 1972 and 1989 when the beach was still wide. A natural loss of about 600,000 cyd of sand occurred between 1974 and 2009. There was an approximately 70 ft decrease in beach width from 1974 to 2009, with sand moving from Broad Beach to Zuma Beach. The average sand volume change between early 1970 and 2004 was about 21,000 cyy (yd^3/yr), while between 2004 and 2010, the sand volume change was about 35,000 cyy. Erosion was severe in the western part of the beach adjacent to Lechuza Point.

Broad Beach is sheltered from deep-ocean waves by numerous offshore islands. The largest windows from which waves can reach the shoreline at the project site are from the west and southwest, and the predominant summer wave direction is largely open from the south.

The wave climate has varied over the years. For example, wave events tended to be moderate between the mid-1940s and mid-1970s when La Niña (cool water temperature periods of low wave energy and low rainfall) conditions were typical. The wave climate changed over the next 20 years from 1978 to 1998 with the onset of El Niño weather conditions (periods of local warm water and corresponding large storms and high rainfall). There was an increase in the number and intensity of extreme wave events. High-energy winter waves approached the coastline from the west or southwest, and the shorter-period summer waves were from the south. More recently, between 2000 and the present, the wave climate has generally been mild.

The simulation of the wave data in front of Broad Beach from 2000 to 2008 by O'Reilly and Flick (2008) shows that waves at Broad Beach are mild. Most of the time, they are less than 4 ft (1.25 m) high, with only 3 or 4 wave storms having reached heights greater than 7 ft. The predominant longshore and cross-shore sand transport at Broad Beach is to the east and onshore respectively, except during large storms. The figures by O'Reilly and Flick (2008) presented in Appendix A show that waves larger than 5 feet from the west and southwest windows (during the winter season) transport sand eastward and offshore, and these waves are responsible for transporting most of the sand from Broad Beach to the east. This pattern was noticeable during the whole measurement time period (2000 through 2008).

The erosion of Broad Beach between the late 1980s and the present is due to: 1) a reduction in the sand supply from the west; and/or 2) a change in the wave climate (i.e., increase in the number of wave storms, their intensity, direction, and duration from the west and southwest windows); and/or 3) a change in the wave-breaking angle with respect to shoreline orientation. Because of the absence of historical directional wave data prior to the 1980s and limited beach profile data, it is difficult to determine the exact reason for the historical periods of erosion and accretion at Broad Beach.

The beach profile of 1970 (Figures 3-6 and 3-7) shows that Broad Beach, at its widest configuration, had a berm height of 12 ft MLLW and a beach face slope of 1:6 (8°). Broad Beach has a steep beach face slope, indicating that the sand grain size is coarse. This information, along with the beach profiles presented in Appendix B, provides a good basis for the design of a successful beach nourishment project at Broad Beach.

M&N (2010) have presented five theoretical methods of estimating the longevity of nourishment sand on Broad Beach and one numerical method using the GENESIS computer model (M&N, 2012a,b). The results of these theoretical methods indicate that nourished sand would stay on the beach for a time period ranging from 5 to 8 years for each nourishment event. This estimate can be low as 3-4 years for each beach nourishment event. The uncertainty of the results is due to the estimation of initial sand losses, which are usually 25% to 40% of the total placed volume. Initial sand losses immediately following the placement of sand on the beach are difficult to estimate; such losses depend on wave conditions during and after placement and on construction techniques to maintain the sand on the beach. To increase the residence time of sand on Broad Beach, we recommend tapering the beach fill, such that its width is greatest in the middle and lessens near both ends, especially since the eastern part of Broad Beach is wide.

The Genesis modeling, which concludes that newly placed sand could erode in as few as 5 years, appears to constitute a worst-case scenario, which may not account for all variables. For example, based upon historic sand losses from Broad Beach of 30,000-40,000 cubic yards per year during periods of relatively active wave climate, the 450,000 cubic yards of sand placed on the beach could be expected to last for 8 to 10 years (or more), still leaving the potential for some residual nourishment sand to remain on the beach as a buffer for the newly created dunes, taking into consideration that the waves at Broad Beach are generally mild (O'Reilly and Flick, 2008) and the impacts of ENSO years on the beach are moderate.

The backpassing of sand from the eastern part of Broad Beach to the western part is a useful technique to increase the longevity of the sand on the beach, especially at the western end. Due to environmental constraints (presence of hard substrate habitat on the western part of Broad Beach; Figure 1-2), it is likely that less sand (cyd/yd) will be placed just east of Lechuza Point compared with the central and eastern areas of Broad Beach.

9.0 REFERENCES

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APPENDIX A

WAVE DATA AT BROAD BEACH
(FROM O'REILLY AND FLICK, 2008)

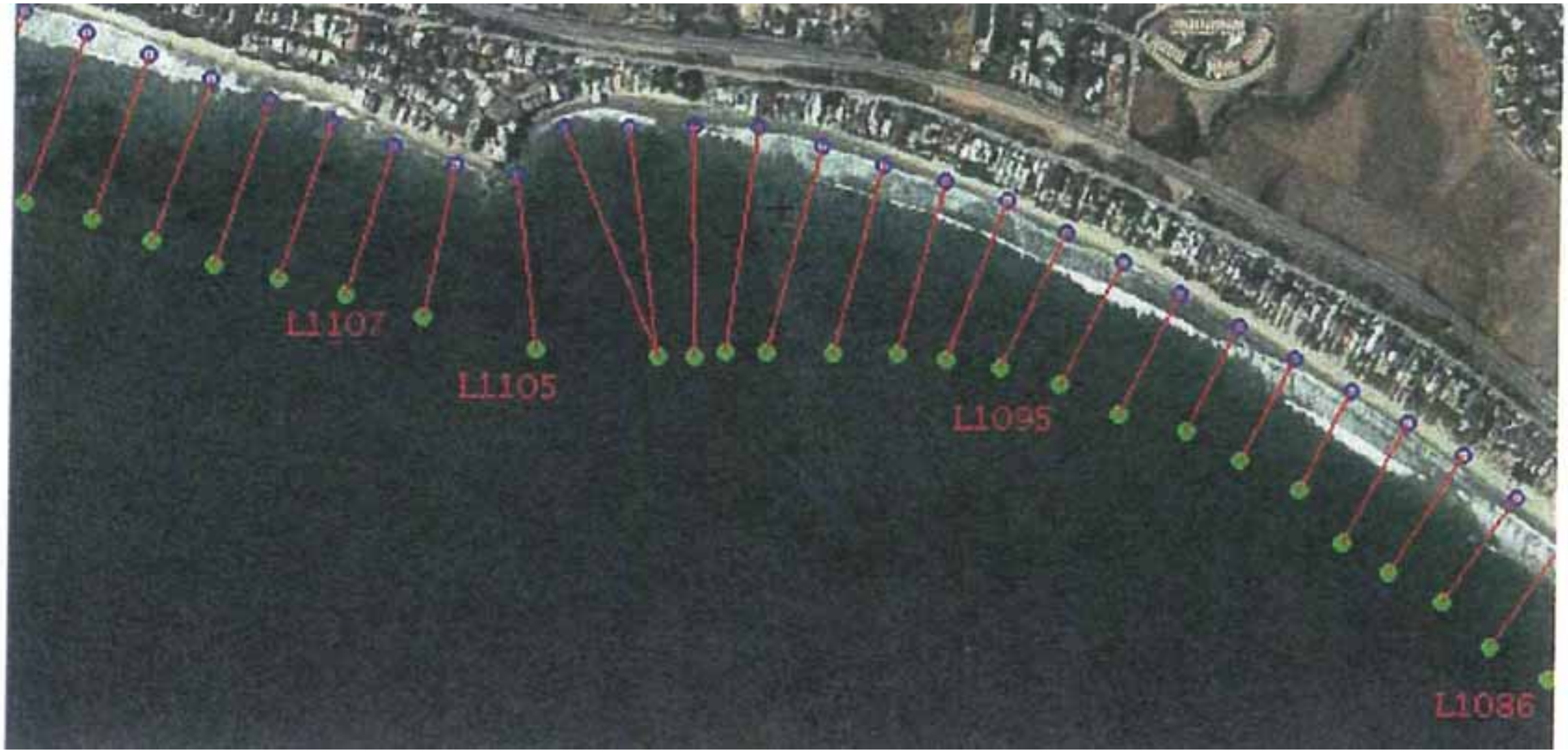

Figure A-1. Map showing Modeling and Prediction (MOP) points (including L1107) for wave modeling results off Broad Beach, Malibu, CA.

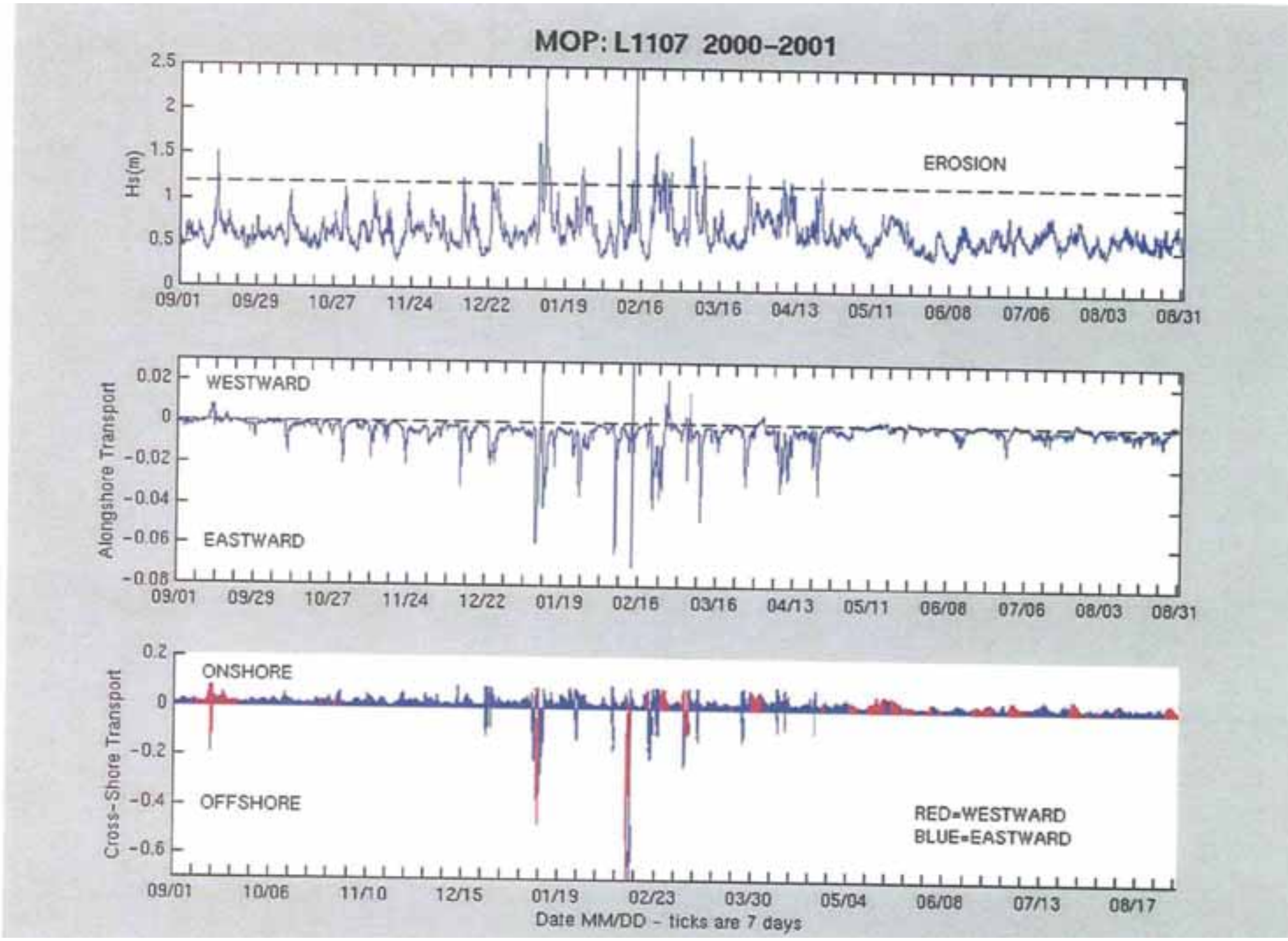

Figure A-2. Significant wave height (upper), longshore wave-driven sand transport potential (middle), and on-offshore sand transport potential (lower) calculated at MOP L1107 for September 2000-August 2001.

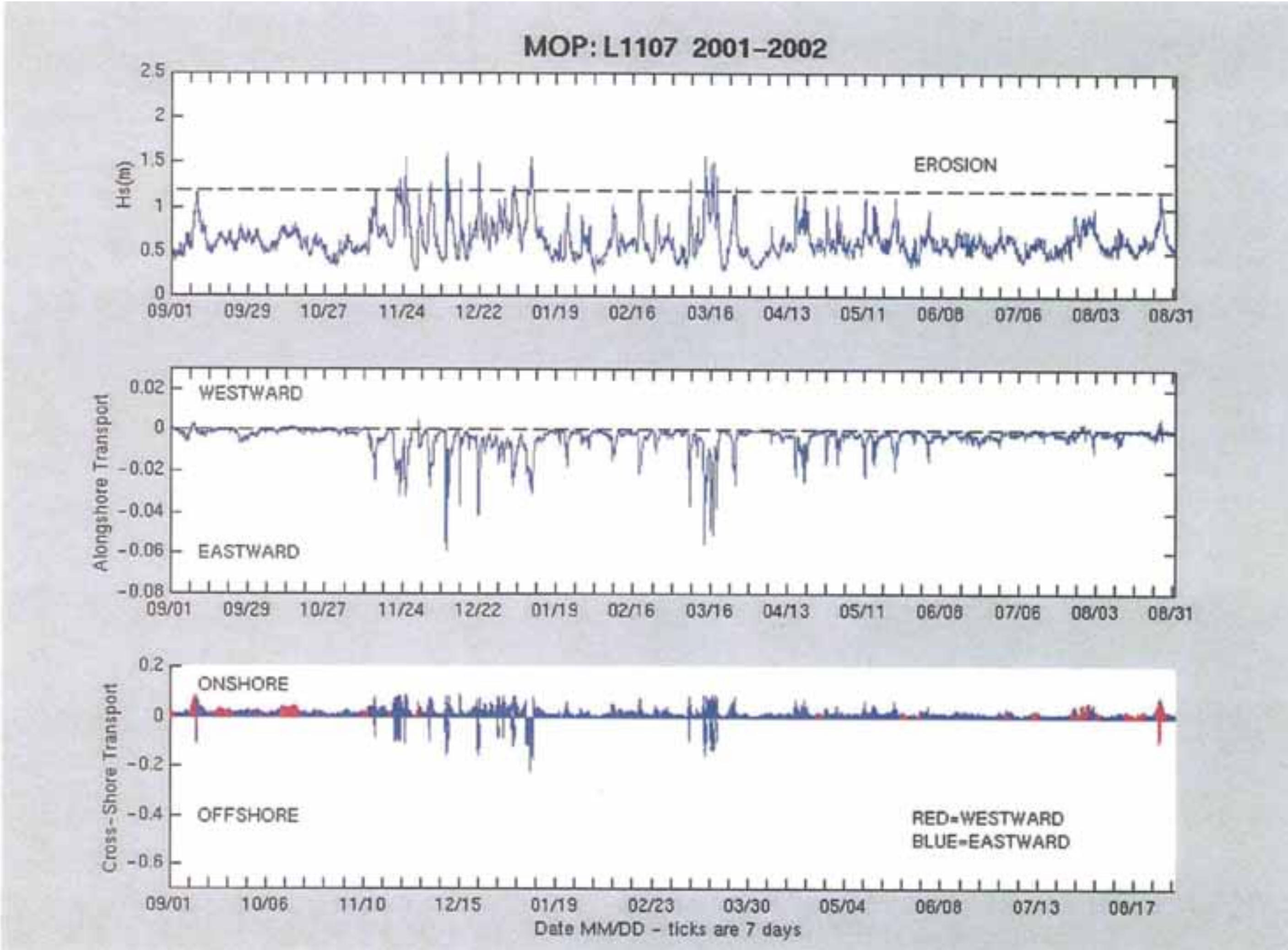

Figure A-3. Significant wave height (upper), longshore wave-driven sand transport potential (middle), and on-offshore sand transport potential (lower) calculated at MOP L1107 for September 2001-August 2002.

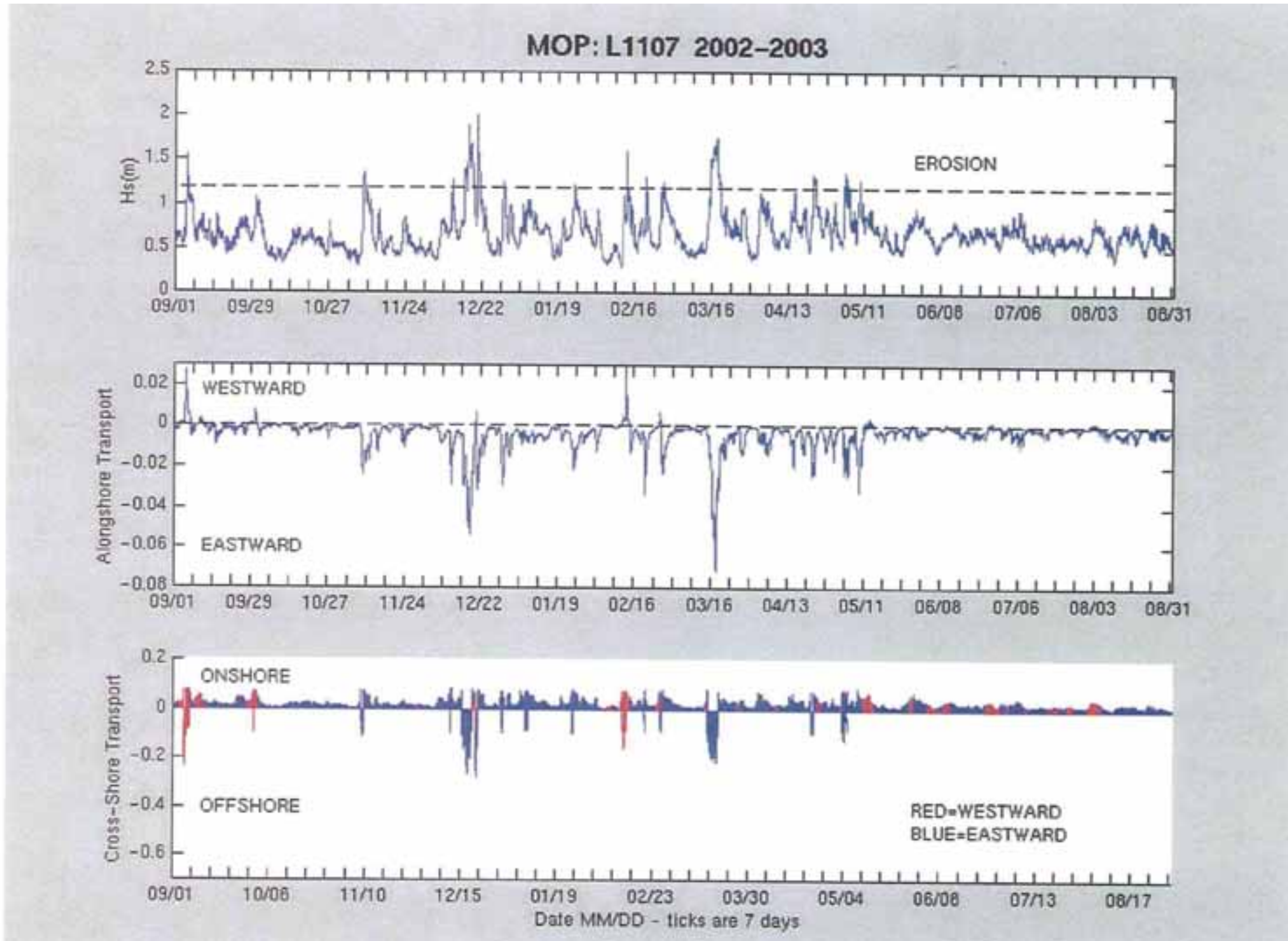

Figure A-4. Significant wave height (upper), longshore wave-driven sand transport potential (middle), and on-offshore sand transport potential (lower) calculated at MOP L1107 for September 2002-August 2003.

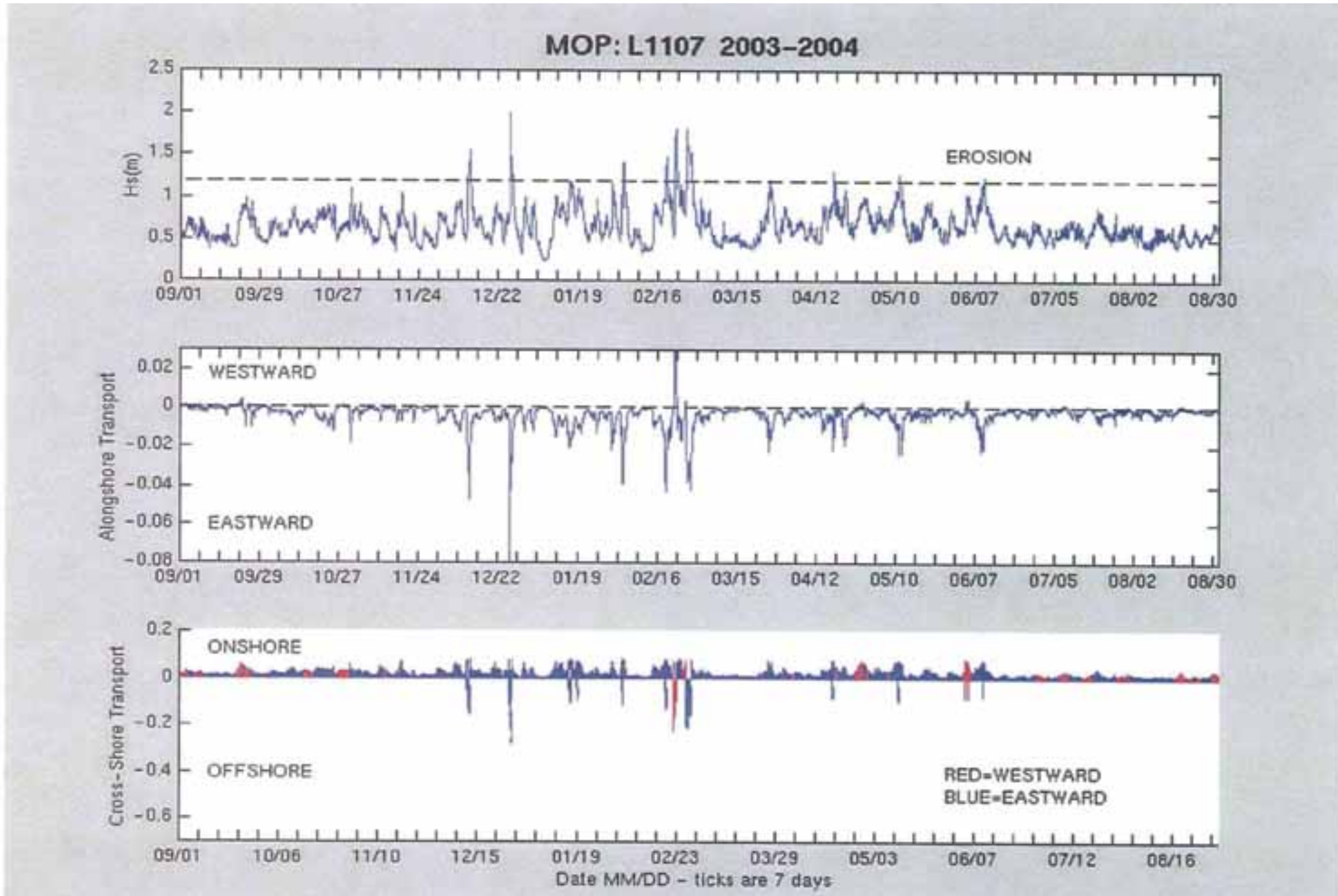

Figure A-5. Significant wave height (upper), longshore wave-driven sand transport potential (middle), and on-offshore sand transport potential (lower) calculated at MOP L1107 for September 2003-August 2004.

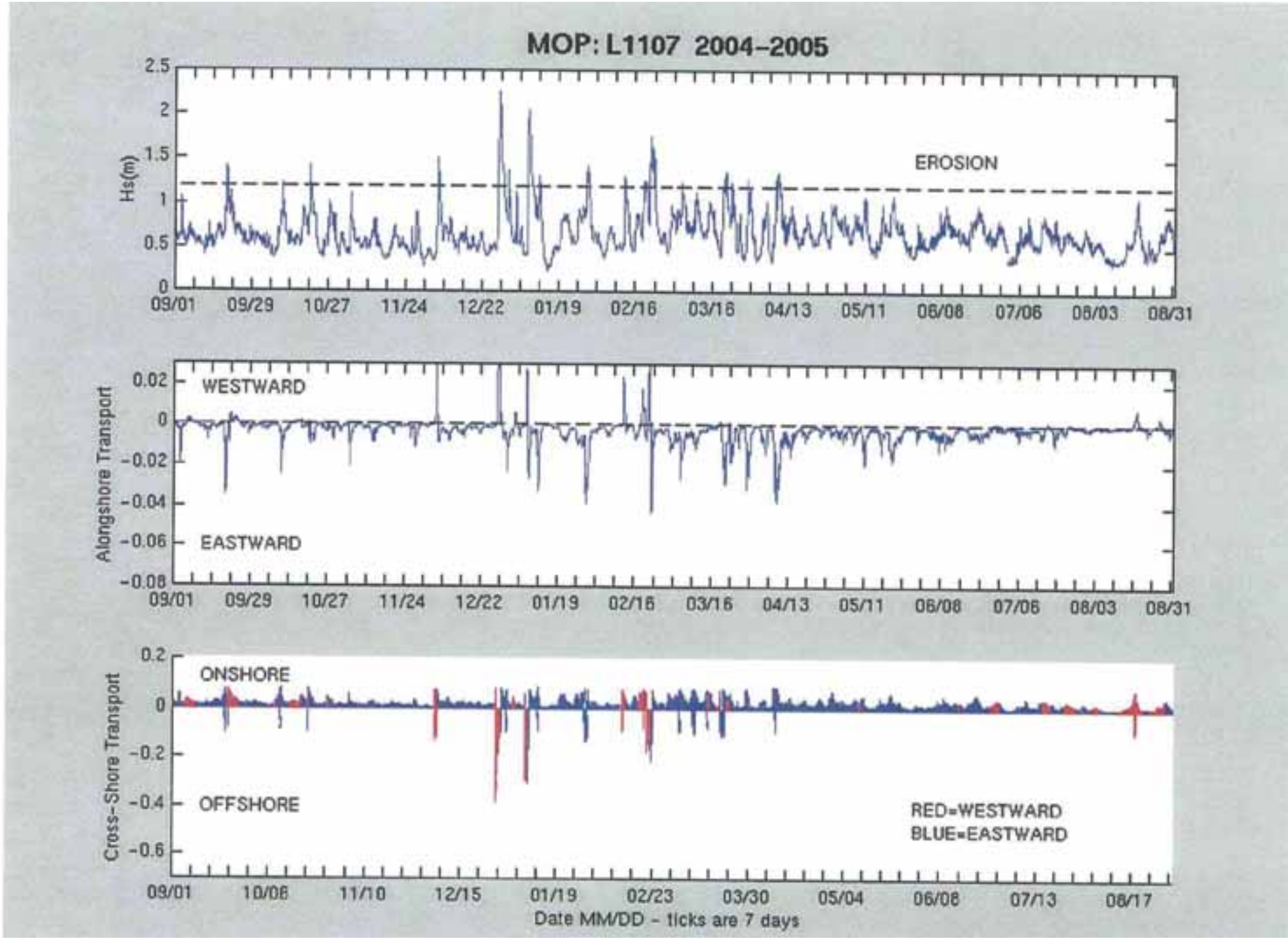

Figure A-6. Significant wave height (upper), longshore wave-driven sand transport potential (middle), and on-offshore sand transport potential (lower) calculated at MOP L1107 for September 2004-August 2005.

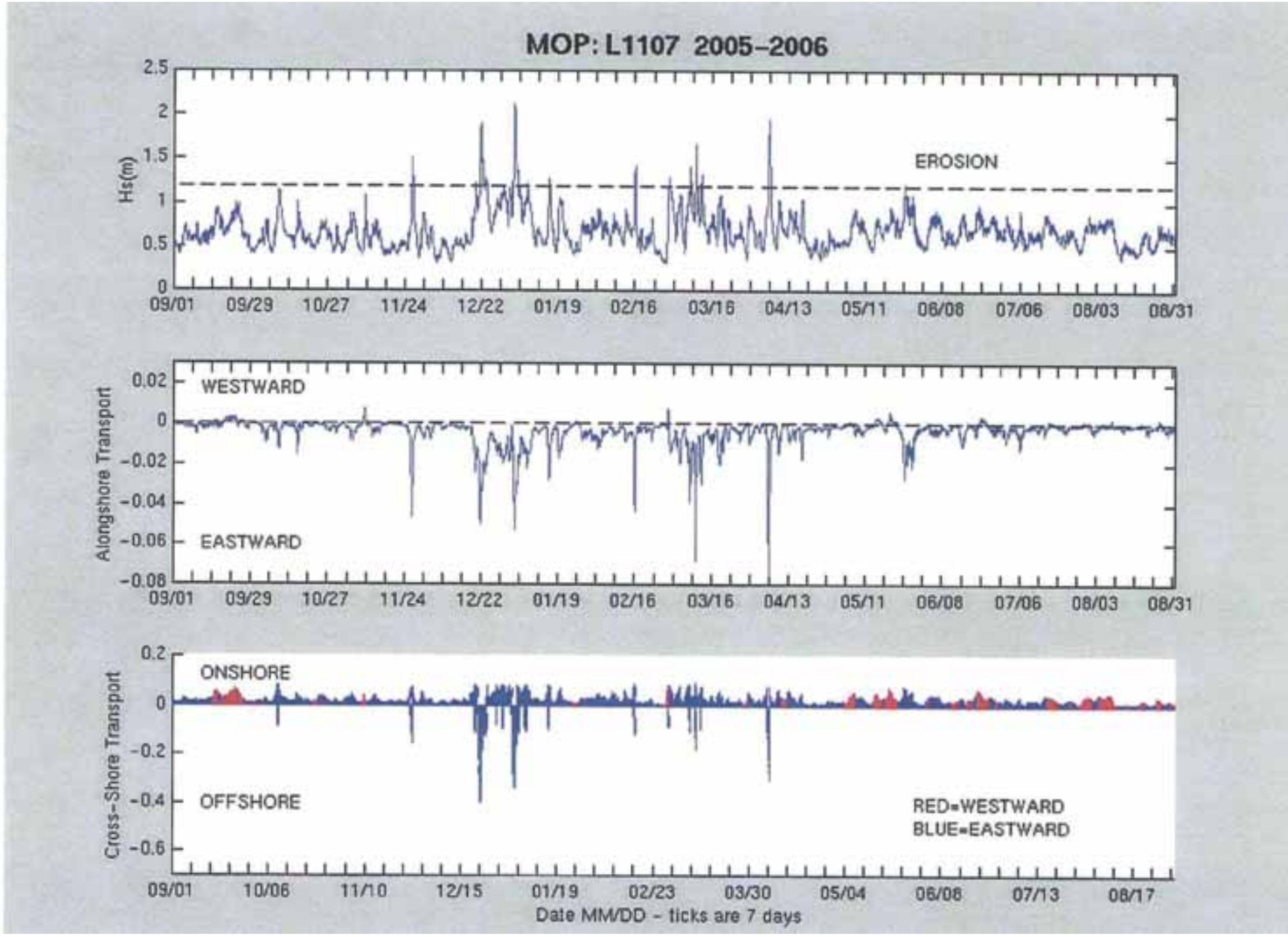

Figure A-7. Significant wave height (upper), longshore wave-driven sand transport potential (middle), and on-offshore sand transport potential (lower) calculated at MOP L1107 for September 2005-August 2006.

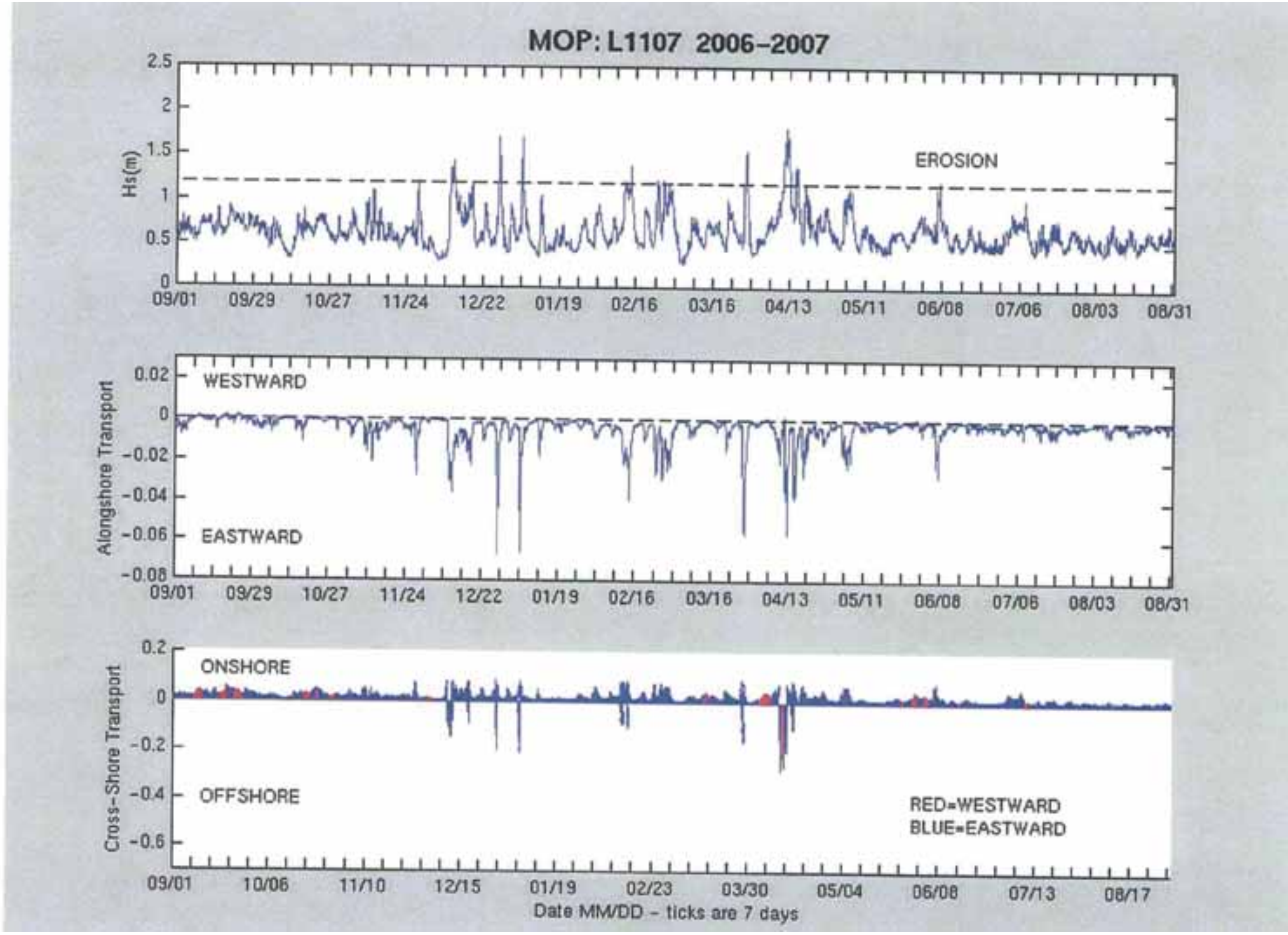

Figure A-8. Significant wave height (upper), longshore wave-driven sand transport potential (middle), and on-offshore sand transport potential (lower) calculated at MOP L1107 for September 2006-August 2007.

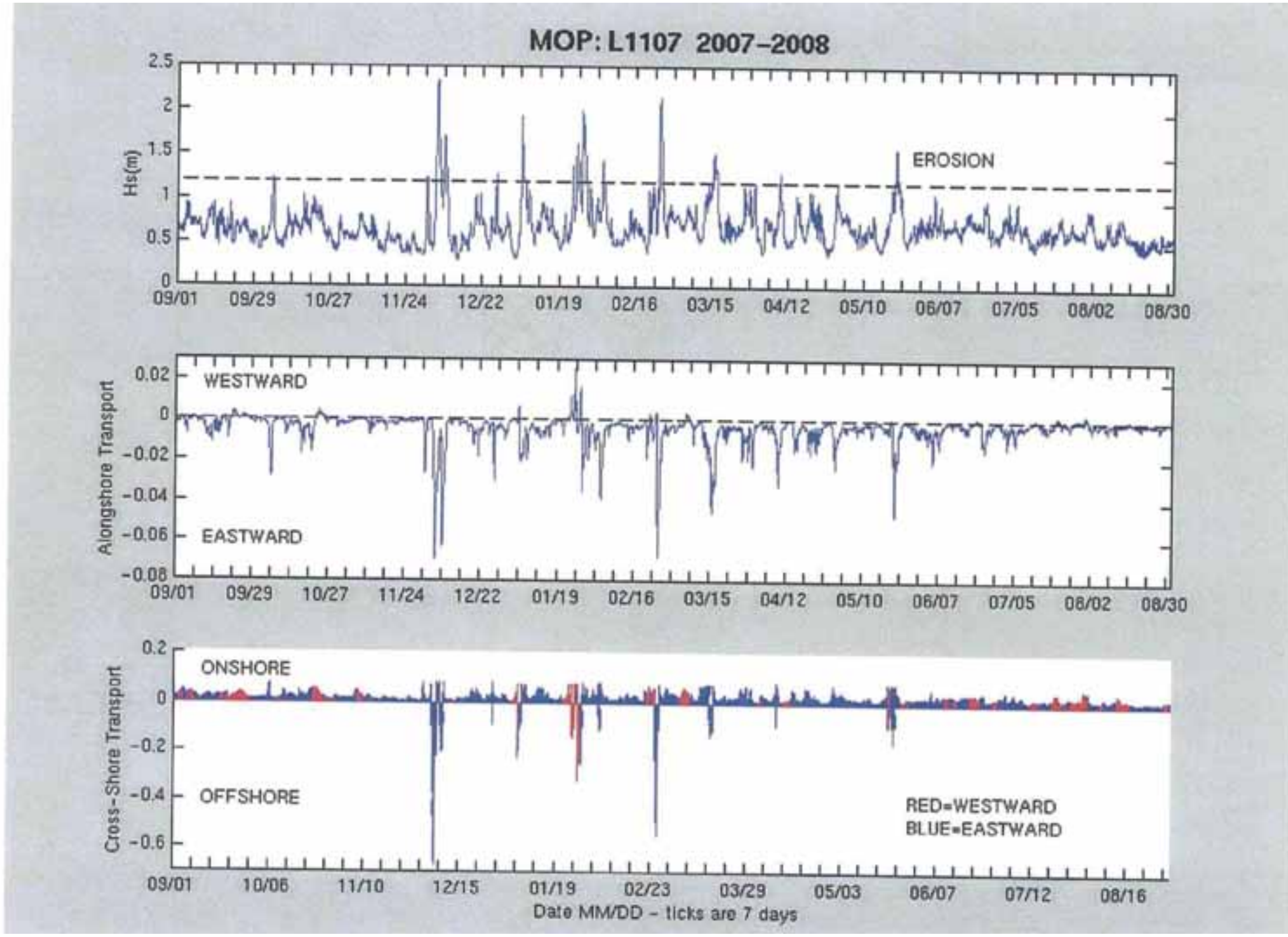

Figure A-9. **Significant wave height (upper), longshore wave-driven sand transport potential (middle), and on-offshore sand transport potential (lower) calculated at MOP L1107 for September 2007-August 2008.**

APPENDIX B

BEACH PROFILE SURVEYS BY COASTAL FRONTIERS AT BROAD BEACH FROM OCTOBER 2009 THROUGH MAY 2012 (4 SURVEYS)

Figure B-1. Broad Beach overview map showing location of transects.

Table B-1. Summary of transect locations.

Transect Designation	Location	Origin [1] Northing (U.S.-Ft)	Origin [1] Easting (U.S.-Ft)	Azimuth (° Grid)
408	30756 Broad Beach Rd.	1,834,503.71	6,305,989.65	219° 40' 30"
409	30916 Broad Beach Rd.	1,835,016.93	6,305,131.68	210° 40' 52"
410	31108 Broad Beach Rd.	1,835,676.64	6,303,789.98	201° 22' 14"
411	31324 Broad Beach Rd.	1,836,223.30	6,302,393.07	201° 22' 14"
412	31506/31504 Victoria Pt. Rd.	1,836,448.10	6,301,017.78	186° 45' 28"

Note:
(1) Horizontal datum is California State Plane, Zone 5, NAD83.

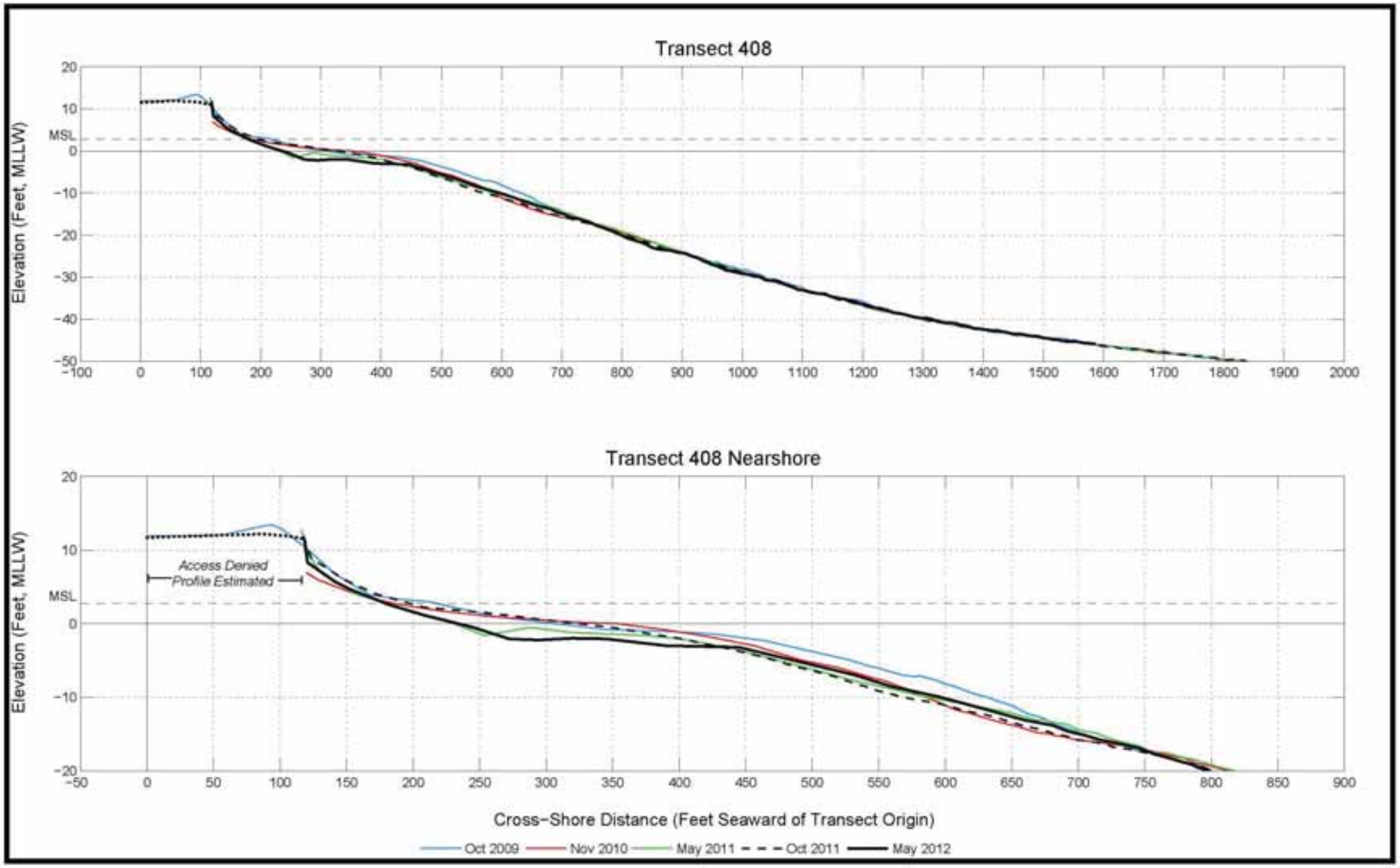

Figure B-2. Beach profiles at Transect 408.

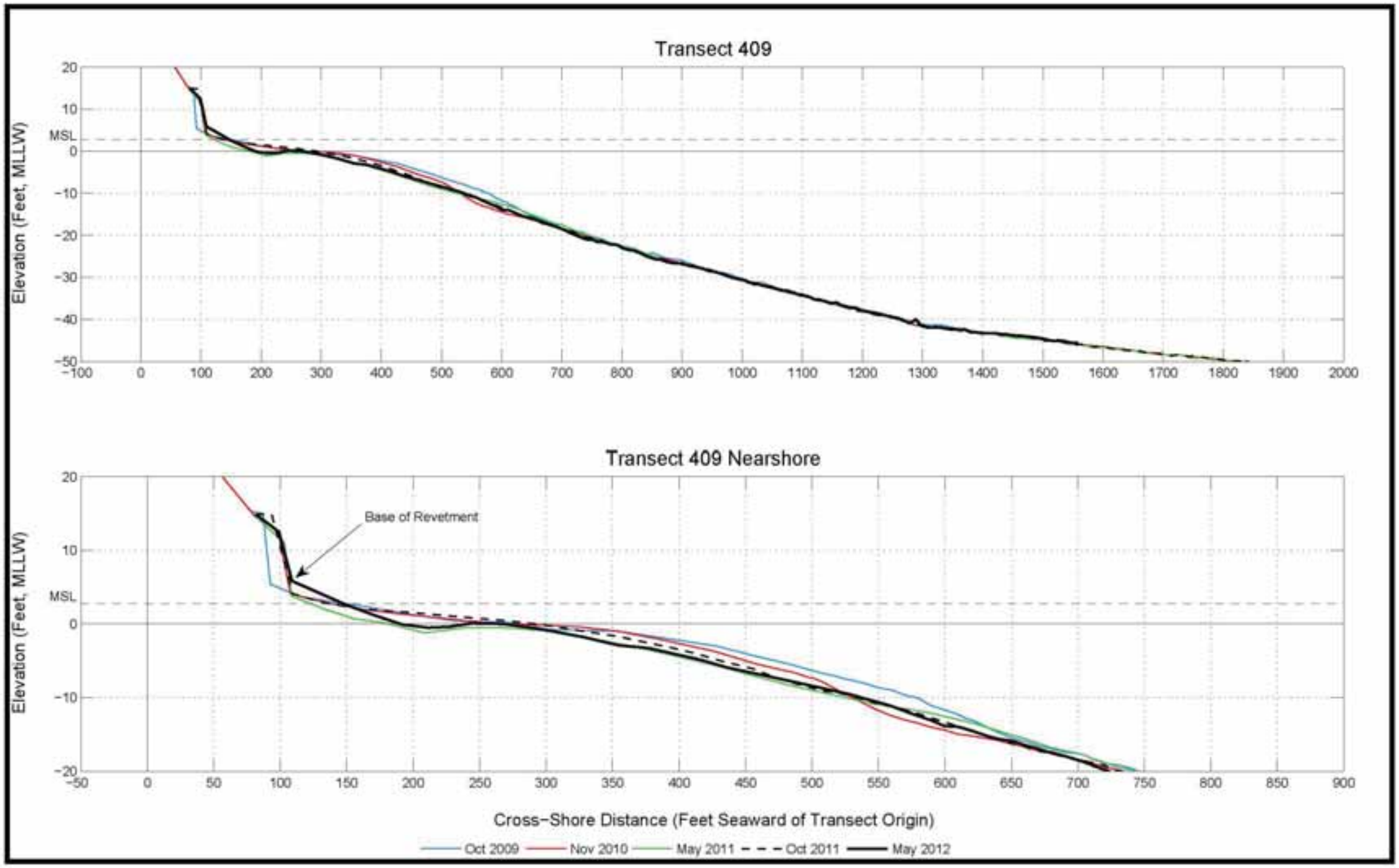

Figure B-3. Beach profiles at Transect 409.

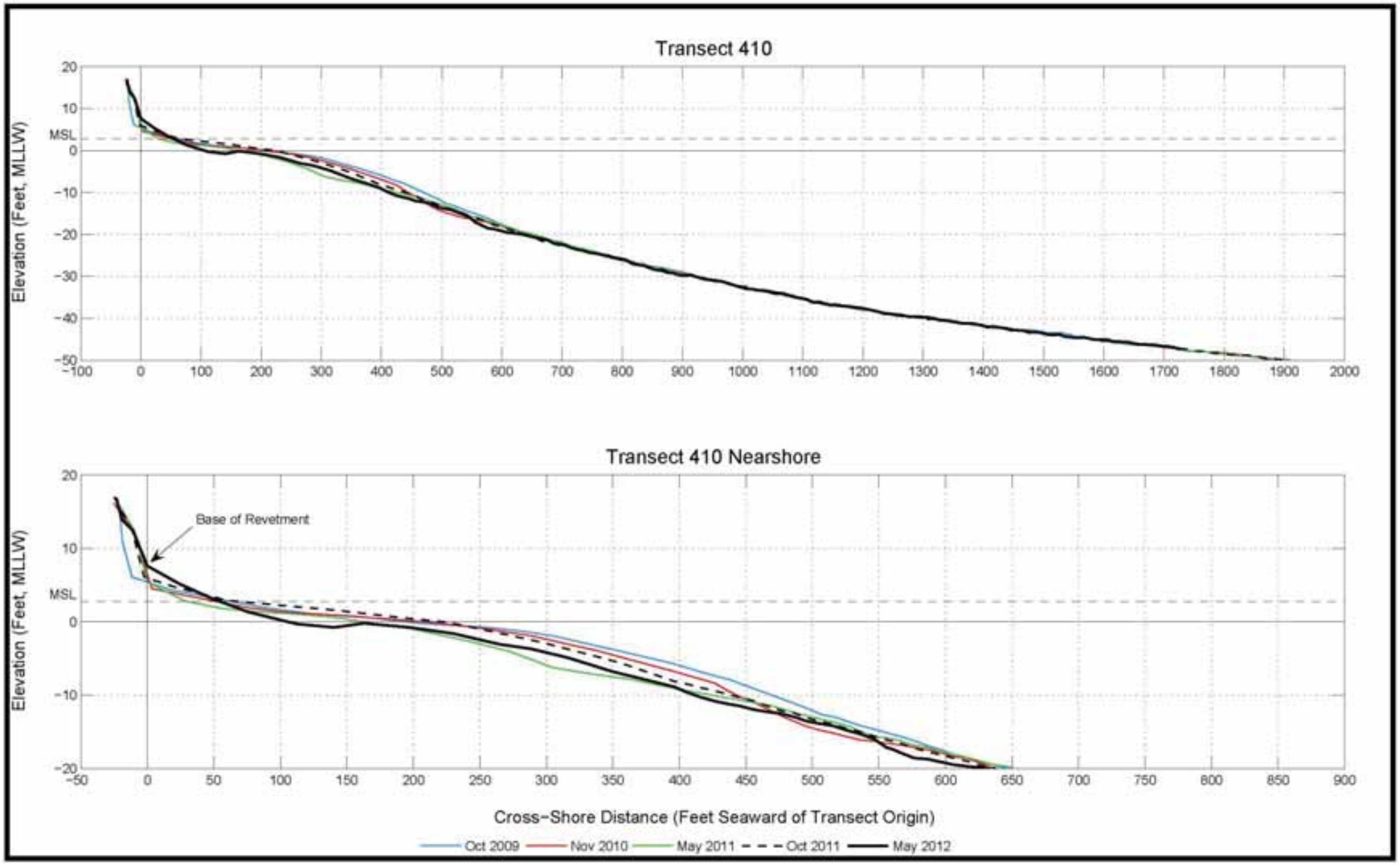

Figure B-4. Beach profiles at Transect 410.

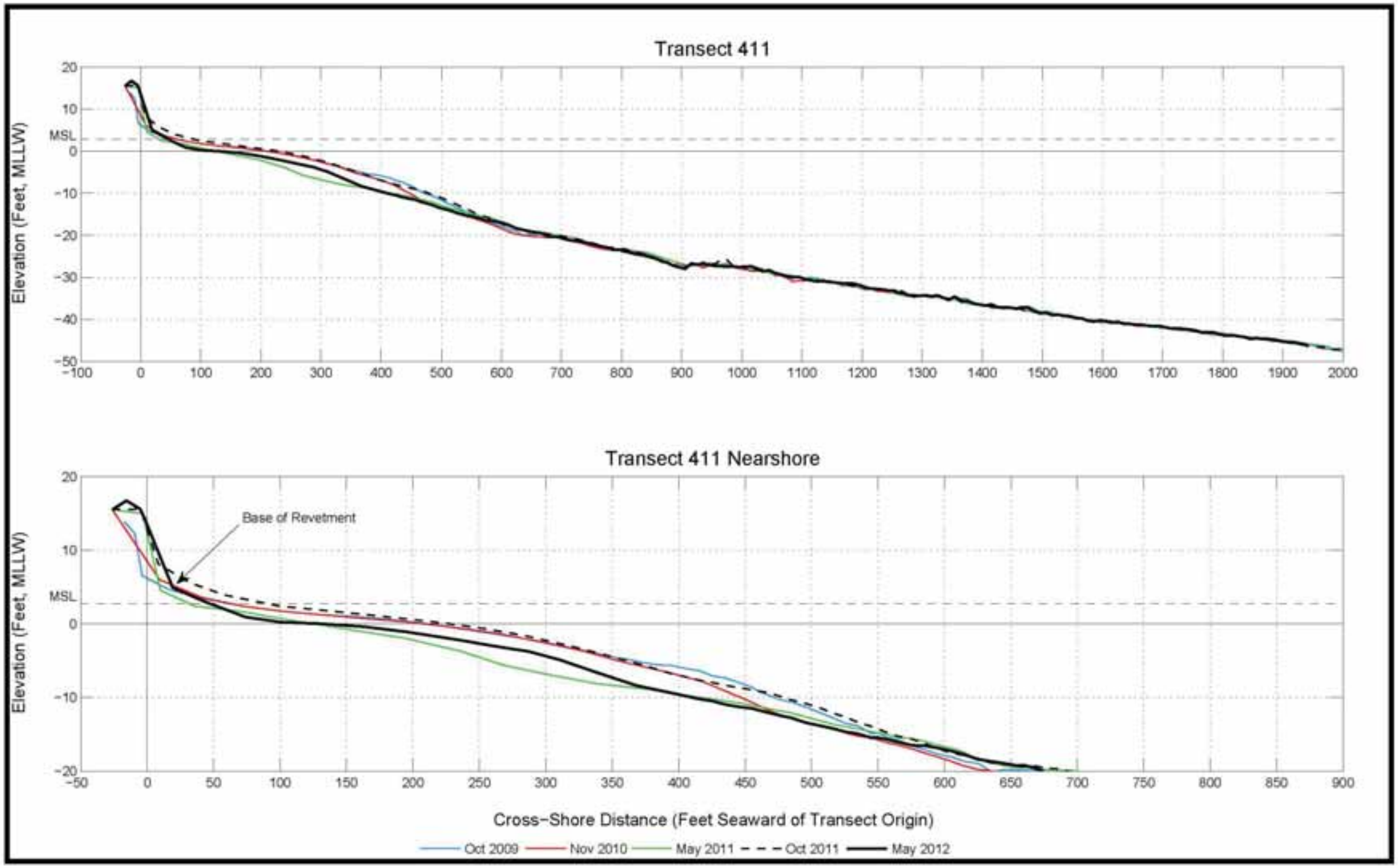

Figure B-5. Beach profiles at Transect 411.

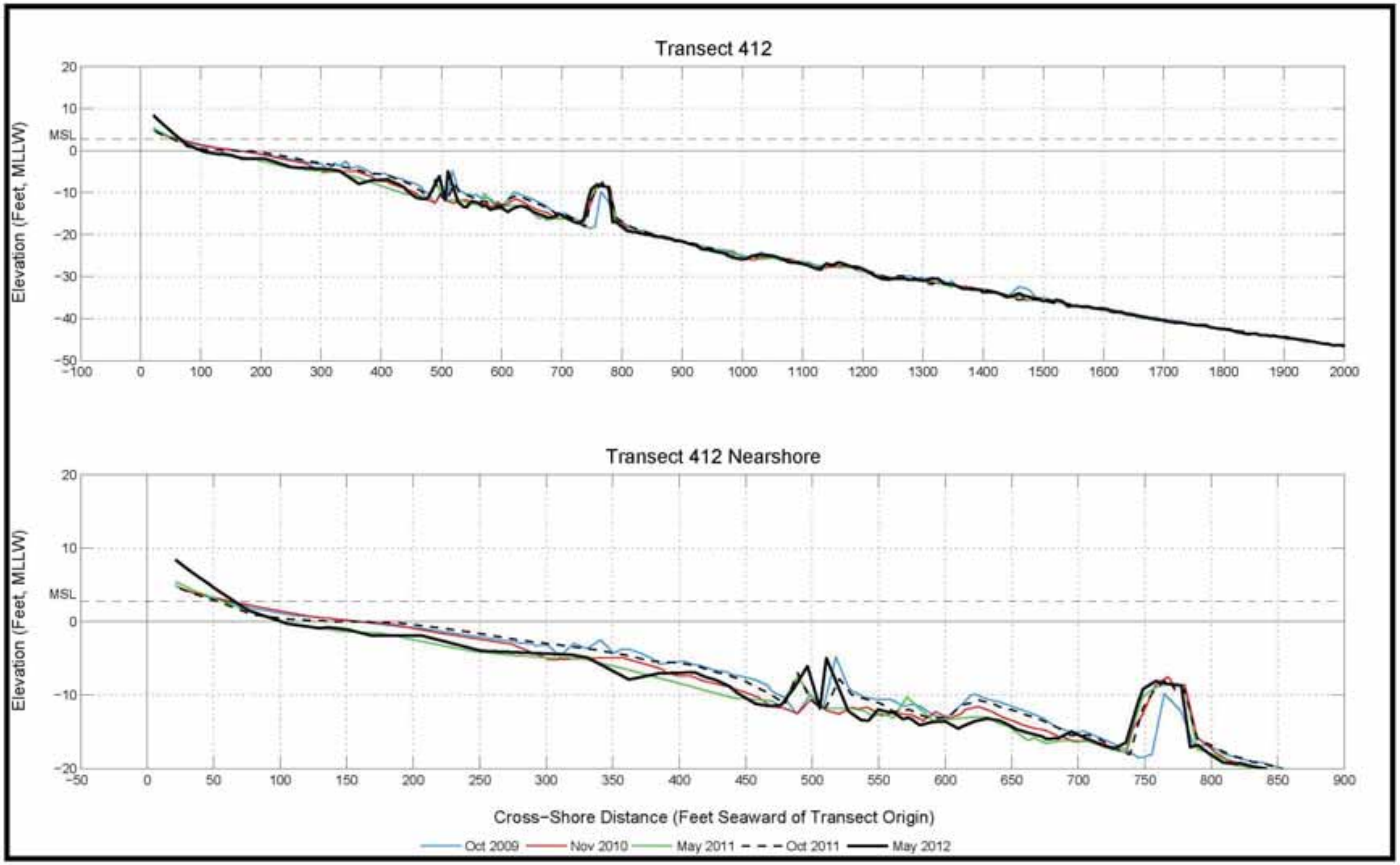

Figure B-6. Beach profiles at Transect 412.

APPENDIX C

FROM MOFFATT & NICHOL BROAD BEACH RESTORATION PROJECT PHASE I REPORT, SECTIONS 5-1 TO 5-5 (APRIL 2012)

APPENDIX C

FROM MOFFATT & NICHOL BROAD BEACH RESTORATION PROJECT PHASE I REPORT, SECTIONS 5-1 TO 5-5 (APRIL 2012)

5.1 ESTIMATE ONE: METHOD BASED ON SHORELINE ROTATION WITHIN A HOOK-SHAPED BAY

Maximum rotation of the shoreline at Broad Beach was approximately midway between Lechuza Point and Trancas Creek. With a shoreline retreat there of about 80 ft and a gradually lessening retreat distance toward Trancas Creek, its angle of rotation was 1.3 or 1.4 degrees. This clockwise rotation occurred as the shoreline adjusted toward a bearing in which ∂Q_n / ∂x was closer to zero. The cause in the rotation was either a decline in the sand supply or an alteration in the longshore component of energy flux, P_{ls}, with the latter resulting from a changed wave climate. In either case there must have been a reduction in the dominant angle between breaking waves and the shoreline.

Given a shift in the bearing of the shoreline of 1.4 degrees without a change in the incident wave approach direction, the net longshore sand transport rate Q_n might have declined about 5 percent (a 5% decline in P_{ls} in Equation 5 and Q_n in Eq. 6) which would translate to a decline in the Fugro McCelland (1995) estimate of Q_n (225,000 cyy) by about 10,000 cyy. Interestingly that is within a factor of 3 of the 2007 sand loss rate based on the CERC formula. With MOP data (Appendix B) applied in the CERC formula the result is a 2000-2008 average Q_n of 115,000 cyy or about half the 225,000 cyy that Fugro McClelland estimated for Broad Beach. Doubling the CERC value would bring the net loss attributable to a changed breaking wave angle to about 20,000 cyy or within 2/3's of the measured amount in 2007. With a westward shift in the dominant incident wave approach direction the change in Q_n would be greater. Carrying this concept a bit further, if the shift in the approach direction of incident waves caused the recent loss of sand at Broad Beach, and it resulted in a 600,000 cy sand loss over 30 years, the loss rate for the beach fill if it duplicates the hooked shoreline planform would be as shown in Figure 40.

5.2 ESTIMATE TWO: METHOD BASED ON SHORELINE RETREAT

This method yields nearly the same result as that of the first method, but the control is a reduced sand supply. To begin, if the shoreline indentation, ***b*,** increases at Broad Beach, the positive $\partial Q_n / \partial x$ (and sand loss rate) will decline, a physically realistic assumption. Next, if the relationship in Figure 36 is valid and the sand supply stabilizes, the relationship between shoreline position at Broad Beach and sand loss due to shoreline disequilibrium is valid. This assumption is questionable since the problem at Broad Beach may be due to a changed wave climate. However, using Figure 36 to estimate the rate of sand loss if the beach is artificially widened to its 1974 position (that is, to reduce ***b*** by 70 ft to 1800 ft) implies that the supply would have to be increased by 35,000 cyy in 2009 to maintain it (if the planform is like the 1974 planform). Finally, one might argue the loss rate due to a disequilibrium shoreline position would be 35,000 cyy in 2009, thence declining every year thereafter. With the addition of this loss rate to the natural loss rate for the next 10 years, the total loss rate would be as shown in Figure 40, with the sum of the natural sand loss and the loss due to a declining disequilibrium planform remaining equal to 70,000 cyy for the life of the beach fill.

5.3 ESTIMATE THREE: NETHERLANDS METHOD

Verhagen (1990) describes an approach that assumes the beach will erode at the same rate as it did before the project plus an additional amount to account for spreading losses and the loss of fines. The supposition is that the effect of an artificially-introduced disequilibrium in the planform will increase the previous sand loss rate by 40 percent. The accuracy, of course, is only as good as the historic survey data and the assumption that the past is a quantitative key to the future. Application of this approach at Broad Beach means that, from Equation 1,

$$\frac{dVa}{dt} = 1.4 \ \frac{dVn}{dt}. \tag{1}$$

5.4 ESTIMATES FOUR AND FIVE: PROJECT DOWNCOAST OF A COMPLETE LITTORAL BARRIER

Campbell et al. (1988) briefly discuss an approach to estimate the rate at which a beach fill will be degraded downcoast of a complete littoral barrier when the bypassing rate is less than the net longshore sand transport rate. Their term for this, *F*, is equal to the bypass rate/net longshore sand transport rate. We used an assumed reduction in the natural net transport rate at Lechuza Point equal to the sand loss rate at Broad Beach in 2007, i.e., 225,000 cy – 32,000 cy/225,000 cy, to define F = 0.85. If supply is the cause this factor accounts for it. We assigned 0.47 as the alongshore diffusivity "constant, G, of the same form as the heat conduction equation,

$$G = (H_b)^{2.5}\sqrt{(g/k)}\,/\,8(s\text{-}1)\,(1\text{-}p)\,(hb\text{+}Zs) \equiv 0.47 \tag{2}$$

in which K = 0.77, H_b = mean wave height at Broad Beach (0.65 m from the MOS wave data, 2000-2008 average), $g = 9.8\text{m}/sec^2$, k = 0.78, s = 2.65, p = 0.35, and $h_b + Z_s$ = distance from the shorebase to the crest of the berm at Broad Beach (11.8 m). We estimated the beach fill disequilibrium loss at Broad Beach with F and G and employed in two ways. The first was through a very approximate fitting of a curve they presented (shown in Figure 40). The second was based on a modification of a deterministic equation they presented to estimate the portion of beach fill that will remain after initial placement, M , with

$$M = \frac{1}{l\sqrt{\pi}}\sqrt{Gt}\ \exp(-1/\sqrt{Gt}^{\,2}) - 1 - \frac{(1-F)Qnt}{lVbf} \tag{3}$$

in which the amount passing the barrier = FQ_n with F = portion of the 1974 net longshore sand transport that passed in 2007, and V_{bf} = volume of beach fill placed (this curve is also shown in Figure 40). Their formula didn't work for us without changing what seemed to be a typo (a minus 1 was included in their exponent, but the equation worked (Eq. 3) when the -1 was entered outside the exponential term).

5.5 ESTIMATE SIX: WORST-CASE SCENARIO, RECTANGULAR FILL DEPOSIT WITH SPREADING AT BOTH ENDS

We concluded our analysis with this scenario to illustrate the worst case outcome for Broad Beach. Dean and others (1988) present a deterministic approach to predict fill loss where the beach is long and straight and the fill is rectangular with no tapering at the ends. Although these conditions are not appropriate to the BB situation, it is instructive to note the resulting rate of loss is inversely proportional to the length of the fill reach squared. They defined the portion of fill remaining at the site in years after placement as

$$M \cong -\frac{2}{\sqrt{\pi}}\frac{\sqrt{(Gt)}}{l} \tag{4}$$

in which *l* = length of the fill (we assume this is the length of Broad Beach or 1.9 km). The results are the worst case outcome because in Equation 4 transport is away from the fill site in both directions and the fill is not tapered at its ends while at Broad Beach the fill is unlikely to spread west around Lechuza Point and it will be tapered in a downdrift direction.

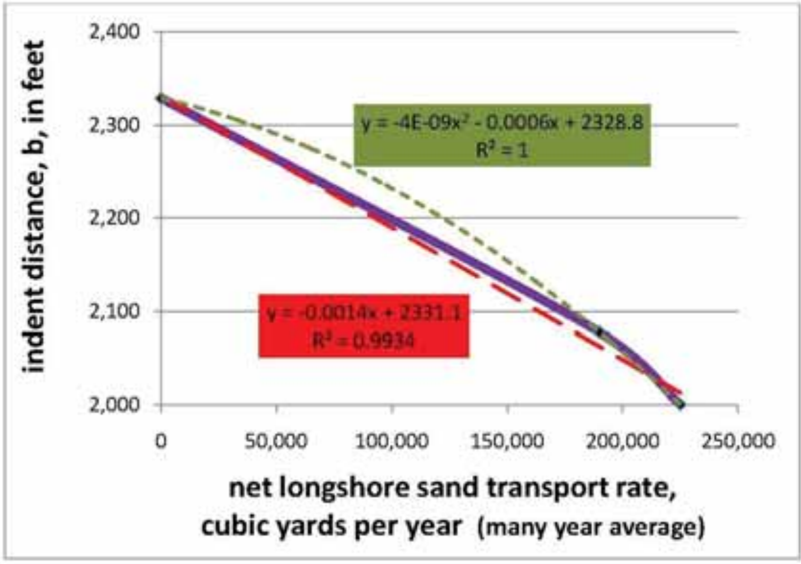

Figure 36. Indent distance, b as a function of sand supply, Q_{nLP} to Broad Beach.

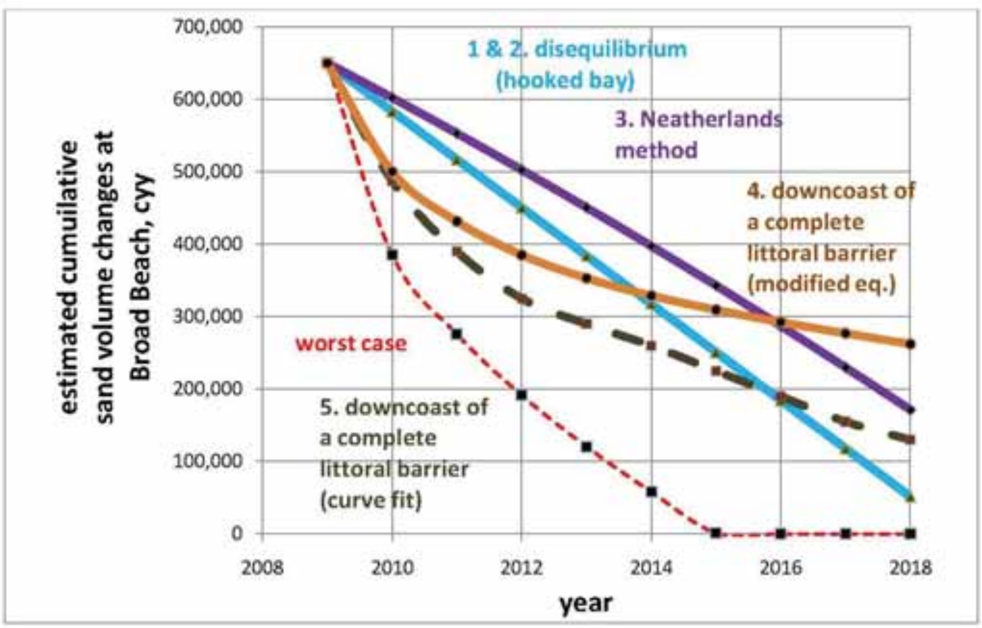

Figure 40. Summary of sand loss estimates at Broad Beach if 600,000 cubic yards of beach fill is placed in 2009 to advance the shoreline an average 70 feet after the profile has equilibrated; estimate is based on a placement planform that is widest near Lechusa Point then tapering to near zero at Trancas Creek.

APPENDIX D

HISTORICAL PHOTOGRAPHS OF BROAD BEACH*

*Photos D-5, D-6, D-10, D-11, and D-13 through D-27 are from the California Coastal Records Project (CCRP) and are copyrighted.

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