3.1 COASTAL PROCESSES, SEA LEVEL RISE, AND GEOLOGIC HAZARDS

This section of the Revised Analysis of Impacts to Public Trust Resources and Values (APTR) describes and analyzes the coastal processes, climatic conditions, and geological hazards present at Broad Beach in the city of Malibu, Los Angeles County (see Figure 1-1). The analysis focuses on issues that are relevant to the objectives and potential impacts of the proposed Broad Beach Restoration Project (Project) on public trust lands, resources, and values. As noted in Section 2, *Project Description*, the Broad Beach Geologic Hazard Abatement District (BBGHAD or Applicant) has identified actions to prevent, mitigate, abate and control geologic hazards at Broad Beach in order to protect homes, septic systems, and other structures from coastal erosion. The Project proposed by the BBGHAD would implement a shoreline protection plan along Broad Beach, including: (1) retention of the existing 4,100-foot-long emergency rock and geotextile sand bag revetments; (2) beach nourishment to create and maintain a wide, dry sand beach; and (3) restoration of a dune system.

The information presented here is intended to inform the California State Lands Commission (CSLC) as it considers whether to issue a lease for those portions of the Project within the CSLC's jurisdiction. Implementation of the Project by the BBGHAD is statutorily exempt from the California Environmental Quality Act (CEQA) pursuant to Public Resources Code sections 26601 and 21080, subdivision (b)(4) (see Section 1, *Introduction*). The scope of review and analysis related to coastal processes, sea level rise (SLR), or geologic hazards includes the CSLC Lease Area on Broad Beach and the broader Public Trust Impact Area (see Figures 1-1, 1-2, and 2-3 through 2-6).

The CSLC Lease Area includes approximately 40.5 acres of public trust lands held by the State (approximately 27 acres of intertidal beach and 13.5 acres of subtidal lands). The Public Trust Impact Area, which encompasses the CSLC Lease Area, extends laterally for approximately 6,200 feet from Lechuza Point to Trancas Creek Lagoon, and vertically from the inland limits of dune construction to the seaward limits of proposed beach nourishment. This area encompasses the approximate 46-acre beach and dune construction area, as well as the construction staging at the west end Zuma Beach Parking Lot 12, stockpiling of imported sand on Zuma Beach adjacent to the parking lot, and vehicle access from the parking lot to Broad Beach; down coast beaches, including Zuma Beach, Point Dume State Beach, and Los Angeles County beaches farther south to Point Dume may be indirectly affected by changes in sand supply and distribution through littoral drift and are also within the Public Trust Impact Area.

The BBGHAD Inland Project Area lies outside the scope of the CSLC's jurisdiction for this Project and includes three quarries in inland Ventura County proposed as sand supply sources, as well as the sand transportation routes inland of Pacific Coast Highway (PCH), that would be used by heavy haul trucks to transport sand to Broad Beach (see Figure 1-2). These areas do not support public trust resources administered by the CSLC related to coastal processes, SLR, or geologic hazards and are not discussed further in this section (see Section 3.7.2, *Traffic and Parking*, for potential traffic impacts from the sand transportation routes). The quarry sites are fully permitted facilities and have been subject to past environmental review by Ventura County; therefore, impacts at these quarries are not analyzed in this APTR.

This section incorporates data and analyses from the following studies (Appendix B):

- Moffatt & Nichol (2010, 2012, 2013) studies prepared for the Applicant regarding oceanographic and coastal processes in the Public Trust Impact Area (the 2010 and 2012 studies underwent third-party review by Coastal Environments, an independent oceanographic and coastal process firm [see Appendix B]);
- Everts Coastal (2009, 2012, 2014) regarding sediment sources;
- Patsch and Griggs (2006, 2007) studies on the Santa Barbara and Santa Monica Bay littoral cells and sediment budgets, and other data and analyses from general studies on California littoral cells; and
- a 2012 analysis performed for an independent investigation of the stability of the rock revetment prepared by Clevenger Geoconsulting and Cato Geoscience.

3.1.1 Coastal and Geologic Setting Relative to the Broad Beach Area

The Southern California coast is subject to a range of climatic and coastal processes, and geologic features as discussed in more detail below. In order to help the reader better understand these processes, this section begins with a summary of key coastal and geologic processes in the Broad Beach area. Topics include:

- Littoral cells;
- Longshore transport;
- Sediment sources and sinks;
- Wave climatology;
- El Niño Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO);
- Sea Level Rise;
- Water levels;
- Shoreline positions
- Historic beach profile and shoreline measurements;
- Sediment transport measurements;
- Geologic and tectonic setting;
- Liquefaction; and
- Tsunamis.

Littoral Cells

A littoral cell is defined as a geographical area with a complete cycle of littoral sand sources, transport paths, and sinks. Littoral cells are beach compartments bounded by geographic features such as headlands or submarine canyons that limit the movement of sand between cells. Each compartment consists of sand sources (such as rivers, streams, and coastal bluff erosion), sand sinks (such as coastal dunes and submarine canyons), and beaches, which provide pathways for wave-driven sand movement within a littoral cell. For assessment purposes, littoral cells can be divided into "subcells" based on points, headlands, and other coastal geographic features.

Broad Beach lies within the Santa Monica Littoral Cell and exemplifies a typical Southern California stretch of coastline, comprising a hook-shaped sandy beach backed by coastal bluffs (Illustration 3.1-1). This hook-shaped beach is referred to as the Zuma Littoral Subcell throughout this report (Illustration 3.1-2). The Zuma Littoral Subcell encompasses approximately 4 miles of shoreline between Lechuza Point at the west end of Broad Beach south to the tip of Point Dume, two well-defined headlands that affect wave action and littoral transport along this hook-shaped segment of coast (Figure 3.1-1).

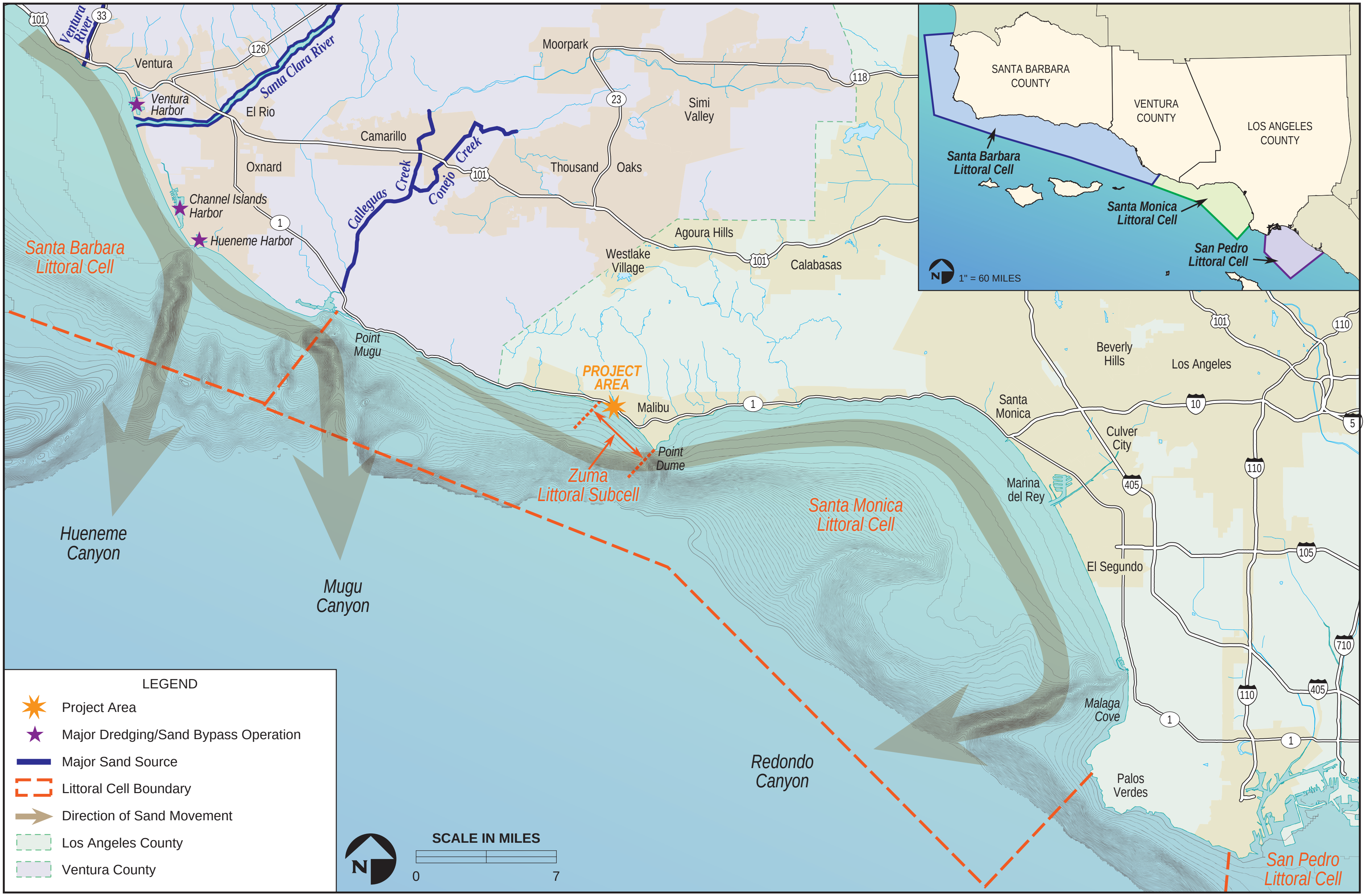
Whereas the littoral zone represents the active sand transport area along the shore, the depth of closure is the littoral cell offshore boundary at which no significant seasonal sand movement occurs either offshore or onshore. The depth of closure acts as the seaward extent to which sand may retreat and return the following season; therefore, it is a meaningful seaward limit for sand addition in beach restoration. The Zuma Littoral Subcell extends to approximately 800 feet from shore with an effective closure depth of 33 feet below mean lower low water (MLLW; the long-term average of shoreline position at lower low tide). Beach sand along the California coast occasionally breaches the depth of closure during severe winter storm events, such as El Niño, when changes in wave direction and increases in wave intensity carry sediment outside of the littoral zone. Once sand is carried outside of the depth of closure, it is lost from the system and does not generally get carried back into the littoral zone by natural forces.

Longshore Transport

Longshore transport, also referred to as littoral transport or littoral drift, is the natural movement of sand along the shoreline. In California, longshore transport generally runs from north to south. Due to the orientation of the beach in the Malibu area, this movement occurs in a generally easterly direction along this coastline, including within the Zuma Littoral Subcell. Wave direction is the primary driver of how the sand moves along the shore. Waves that travel through the Santa Barbara Channel to Malibu from the west (North Pacific swell waves) move sand alongshore from west to east. South swells arriving nearly perpendicular to the Malibu shore move sand in a cross-shore direction, either offshore to deeper water or onshore from deeper water. During winter season, waves higher than 5 feet from the west and southwest transport sand eastward and offshore; 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. The predominant longshore and cross-shore sand transport at Broad Beach is to the east and onshore respectively, except during large storms.

Illustration 3.1-1: *Broad Beach and immediate down coast beaches extend for approximately 4 miles along the Malibu coast. These areas include Broad Beach and its narrow low-tide, generally sandy beach backed by the emergency rock revetment (foreground), and the wide sandy beaches at Zuma Beach and Point Dume State Beach located down coast and further south and east (background).*

Illustration 3.1-2*: The Zuma Littoral Subcell encompasses the Broad Beach area and down coast area beaches and offshore areas extending for approximately 4 miles from Point Lechuza to Point Dume.*



amec

Regional Coastal Sand Transportation and Littoral Cells

FIGURE 3.1-1

Moffatt & Nichol (2013) estimated gross longshore sand transport to be 792,000 cubic yards per year (cy/yr) between 1946 and 1974, and 544,000 cy/yr between 1974 and 2007. Net longshore transport (subtracting sand transport in the opposite direction) was estimated to be 424,000 cy/yr from 1946 to 1974, and 280,000 cy/yr from 1974 to 2007. Moffatt & Nichol concluded that the difference in yearly longshore sand transport from the earlier to the later period resulted from a change in wave conditions, a change that led to noticeable erosion at Broad Beach between 1974 and 2007.

Sediment Sources and Sinks

Due to the wave climate and predominant longshore sand transport direction, Broad Beach depends on sand delivered from upcoast sources, including from coastal watersheds of the Santa Monica Mountains and erosion of coastal bluffs (Illustration 3.1-3). The sedimentary rocks of the Santa Monica Mountains are easily erodible and supply sediment to the adjacent drainages during wet winters. This sediment makes up a portion of the Zuma Littoral Subcell sand budget. The primary drainages in the area are Trancas Creek and Zuma Creek (east of Broad Beach), and Arroyo Sequit, Little Sycamore Creek, Deer Creek, and Big Sycamore Creek (west of Broad Beach). Sediment exiting from area creeks is transported primarily to the southeast by the wave-induced longshore current. The watersheds of these creeks appear to contribute 41,000 cy/yr of sediment to this system between Point Mugu and Point Dume (Everts Coastal 2012), with Trancas and Zuma creeks contributing an additional 8,000 cy/yr to the Zuma Littoral Subcell down coast from Broad Beach (TerraCosta 2008).

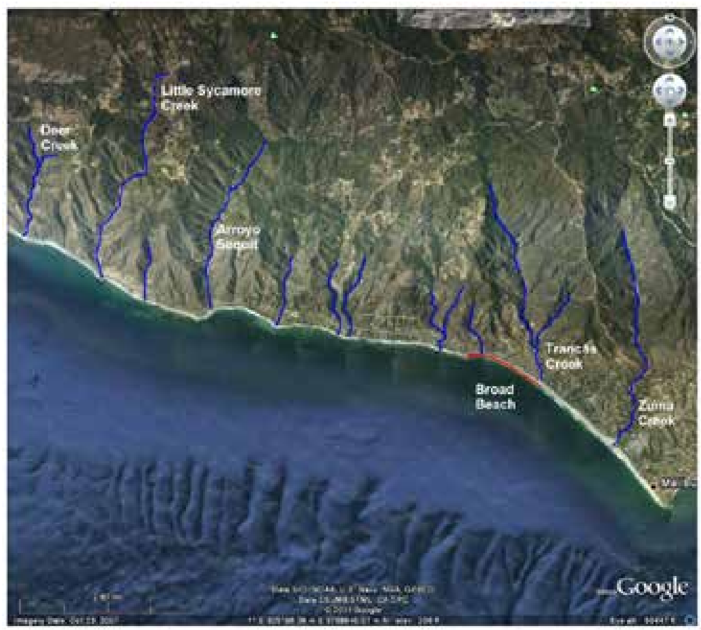


Illustration 3.1-3: *Local creeks carry sediment from the mountains to the sea, acting as a source for beach sand in the Malibu area.*

Historically, a major input of sand into this littoral cell was the construction in 1926 of PCH along the northern Malibu coast. Initial construction contributed an estimated 1.2 million cy of sand that was deposited offshore and acted as beach nourishment. Another approximately 150,000 cy of sand from maintenance of PCH entered the system from cut slopes until the armoring of PCH in the 1960s (Patsch and Griggs 2007). The historic width of Broad Beach and other Malibu beaches may have benefited from this artificial input of sediment. Sediment is also supplied to the ocean in this area through erosion of local bluffs. Bluff erosion is estimated to contribute an average of 7,000 cy/yr of sand between Point Mugu and Point Dume, a reduction of approximately 12 percent (1,000 cy/yr) from historic levels, due to armoring of approximately 3,500 feet of bluffs in this stretch of coast (Patsch and Griggs 2007).

Mugu Submarine Canyon intercepts a large proportion of the longshore sand supply moving south from the Santa Barbara Littoral Cell, and in effect, represents the upcoast limit of potential sand sources for the Santa Monica Littoral Cell. This canyon intercepts a higher portion of longshore sediment transport in its vicinity than any other submarine canyon in California. Based on a study prepared for the U.S. Army Corps of Engineers (USACE), as much as 90 percent of the longshore transport enters the canyon and is lost from a longshore transport rate of approximately 1,065,000 cy/yr (Moffatt & Nichol 2009). However, as much as 140,000 cy/yr of sand from the Santa Barbara Littoral Cell may also bypass Mugu Submarine Canyon and represent an additional sand source for the Broad Beach coast (Moffatt & Nichol 2013). Sand contribution from this source is uncertain, and debate among experts persists as to how much sand passes by Mugu Submarine Canyon and to what extent sand from the upcoast Santa Barbara Littoral Cell contributed to historically wider beach at Broad Beach. Point Dume Submarine Canyon, at the eastern edge of the Zuma Littoral Subcell, is not a major sediment sink, and longshore transport carries a large majority of sand past Point Dume. In total, Point Dume Submarine Canyon captures less than 1,000 cy/yr (Everts 2012).

Wave Climatology

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. As Broad Beach is sheltered from deep-ocean waves by offshore islands (including Santa Cruz, Santa Rosa, San Miguel, San Nicolas, Santa Catalina, and San Clemente) and shoals, only waves from certain directions reach the Project site. These islands block, dissipate, refract, and reflect wave energy thereby modifying the wave conditions along the mainland shoreline. The largest windows from which waves can reach the shoreline at the Project site are from the west and southwest at an angle of 265 to 220 degrees (from true north). The predominant summer wave direction is largely open from the south (from 210 to 170 degrees), as shown in Figure 3.1-2.

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.

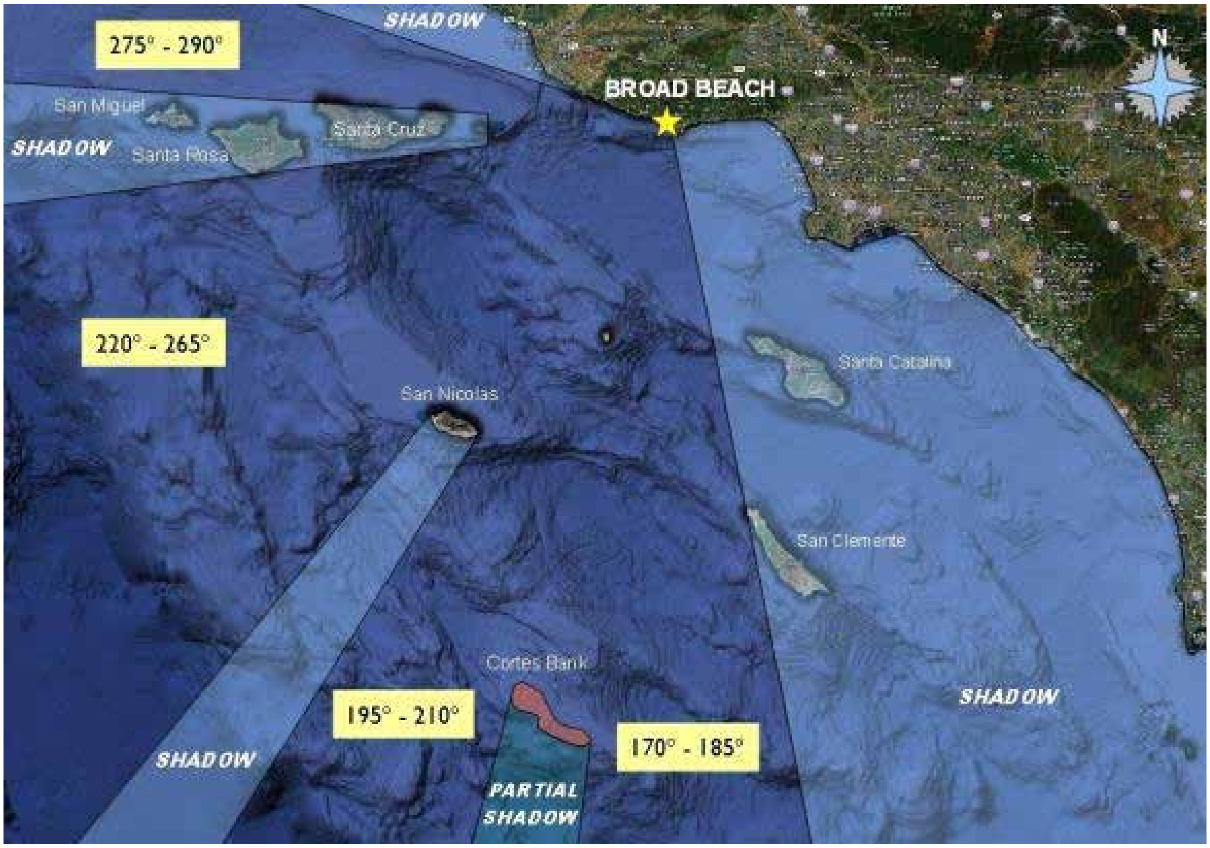


Figure 3.1-2. Wave Exposure Windows at Broad Beach

North Pacific swell events are the most significant source of extreme waves in the region. Swells from winter storms in the southern hemisphere reach California and the Public Trust Impact Area for the Project (e.g., Zuma Beach) during May through October. These swells approach Broad Beach from the southwest, south, and southeast, but are partially blocked by the Channel Islands. Additionally, the great decay distances result in waves of low heights and long periods. Swells generated from tropical storms that develop off the coast of Mexico can also generate high waves, though extreme events in Southern California are rare. Locally generated waves are predominantly from the west and southwest, except for pre-frontal wind-generated waves from the southeast, which occur in winter. Locally generated waves in this area are usually less than 6 feet in height with wave periods less than 10 seconds.

Wave climate varies with time. For example, wave events tended to be moderate between the mid-1940s and mid-1970s when La Niña (i.e., cool water temperature periods of low wave energy and low rainfall) conditions were typical. The wave climate changed during the period from 1978 to 1998 with the onset of El Niño weather conditions (i.e., periods of local warm water and corresponding large storms and high rainfall) that included an increase in the number and intensity of extreme wave events. High-energy winter waves approached the coastline from the west or southwest, while summer waves originated with hurricanes off Central America. More recently, although a combined storm and high tide in March of 2014 created a major wave event, between 2000 and the present, the wave climate has generally been mild.

O'Reilly and Flick (2008) used wave information for the California coast (available from the Coastal Data Information Program) to understand the wave climate at Broad Beach and determine the wave-related causes of the unusual erosion observed in the area during the winter and spring of 2007-2008.[1] The data consist of nearly 8 years of hourly wave height, period, and direction calculated at 330-foot intervals along the California coast, including the area off Broad Beach. O'Reilly and Flick (2008) concluded that, in general, waves at Broad Beach are mild. Most of the time, they are less than 4 feet high, with only a few wave storms having reached heights greater than 7 feet. Between 2000 and 2008, the number of hours per year that wave heights were greater than 5 feet ranged from 0 to 103, with an average of 52 hours. 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.

El Niño Southern Oscillation (ENSO) and Pacific Decadal Oscillation Index (PDO)

Although large waves can happen in any year, historically, the most damaging extreme wave events to affect Southern California have occurred during ENSO events, which represent global-scale climatic variations that tend to occur every 2 to 7 years. During strong ENSO events, sea level along the California coast is elevated by 0.5 to 0.7 feet for up to 2 years at a time (TerraCosta 2008). During these events storms approach from a more westerly direction and typically generate larger waves with longer periods that increase the amount of energy reaching the Southern California coast. Some of the most damaging extreme wave events at Broad Beach occurred during the 1997-1998 and 2009-2010 El Niño events. El Niño conditions (e.g., elevated water levels, increased storm intensity, and westerly wave approach direction) combine to enhance sediment transport rates. As illustrated by recent ENSO events, the effect on Broad Beach is an increase in shoreline erosion and the associated potential for damage to property from wave uprush and overtopping of shoreline protection structures.

The PDO is a pattern of long-term climate variability in the Pacific Ocean that typically has shifted every 20 to 30 years and is described as being in either a warm (positive PDO) or cool (negative PDO) phase. The phases are associated with changes in sea surface temperatures that result in changes to the jet stream path. Changes in beach behavior from accretion (i.e., widening) to erosion may be related to different phases of the PDO (Revell and Griggs 2006). The PDO was negative (i.e., cool) from 1947 to 1977, corresponding to relatively calm, dry weather. The PDO reversed and was

[1] Coastal Data Information Program (CDIP) measures, analyzes, archives, and disseminates coastal environment data for use by coastal engineers, planners, and managers, as well as scientists and mariners. Available at: https://cdip.ucsd.edu/.

positive (i.e., warm) until 1999, corresponding to relatively stormy, wet weather with more intense El Niño effects. After 1999, the PDO has cycled rapidly between cool and warm phases with only 2 to 3 years separating these phases. The PDO is distinct from the ENSO, the cycle that includes El Niño and La Niña, in three ways:

- **Location**. The strongest signature of the PDO is in the North Pacific, instead of the tropical Pacific.
- **Duration**. PDO phases last much longer (typically 20 to 30 years for a single warm or cool phase) than ENSO events (6 to 18 months for a single warm [El Niño] or cold [La Niña] phase. This conclusion is based on 20th century observations and has been confirmed to a significant degree by historic analysis of tree rings (Gedalof and Mantua 2002) and geoduck clam shells (Strom 2003).
- **Cause and Predictability**. The factors contributing to ENSO events allow scientists to forecast ENSO events several seasons in advance of their onset. The causes of the PDO, on the other hand, are not well understood. Newman et al. (2003) suggest that the PDO represents direct effects of the ENSO, the re-emergence of North Pacific sea surface temperature anomalies in years after the ENSO, and random direct effects of atmospheric temperature conditions.

Part of the difficulty in understanding what triggers PDO phase shifts is the persistence of PDO events. Accurate instrumental records for the North Pacific begin around 1900; because of the relatively long 20- to 30-year duration of the PDO phases, only two complete PDO cycles have been observed in the last 110 years, making it difficult to determine the cause for, and predictability of, the PDO. MacDonald and Case (2005) reconstructed the PDO back to the year 993 using tree rings from California and Alberta. Their index showed a 50- to 70-year periodicity occurring only after 1800; a persistent negative phase occurred during medieval times (993 to 1300) which is consistent with La Niña conditions reconstructed in the tropical Pacific (Rein et al. 2004) and multi-century droughts in the southwestern U.S. (Seager et al. 2007).

Studies suggest that ENSO effects on North American climate are strongly dependent on the phase of the PDO, such that “strong” El Niño and La Niña patterns are only observed during years in which ENSO and PDO extremes are “in phase” (i.e., with warm PDO and El Niño, and cool PDO and La Niña, but not with other combinations) (Gershunov and Barnett 1998; Gershunov et al. 1999; McCabe and Dettinger 1999).

Scientists believe we may have currently entered a negative (cool) phase of the PDO (University of Washington Climate Change Impacts Group 2012; NASA 2012). Although this could result in reduced storm intensity, the effects of this cycle on Broad Beach cannot be determined, as beach erosion appears to be continuing. Although these overall patterns may indicate a calmer wave climate more conducive to reduction in erosion or limitations in storm damage, this patterns is not evident from empirical monitoring. Therefore, even if this PDO reversal has occurred, there is no observed evidence that beach accretion that historically occurred up to 1970 will return. As discussed under *Sediment Sources and Sinks* above, this may be due to regional factors such as a decline of past sediment inputs into the system from sources such as PCH construction, fires or floods or to increased interception of down coast littoral drift of sand from the upcoast Santa Monica Littoral Cell by the Mugu Submarine Canyon.

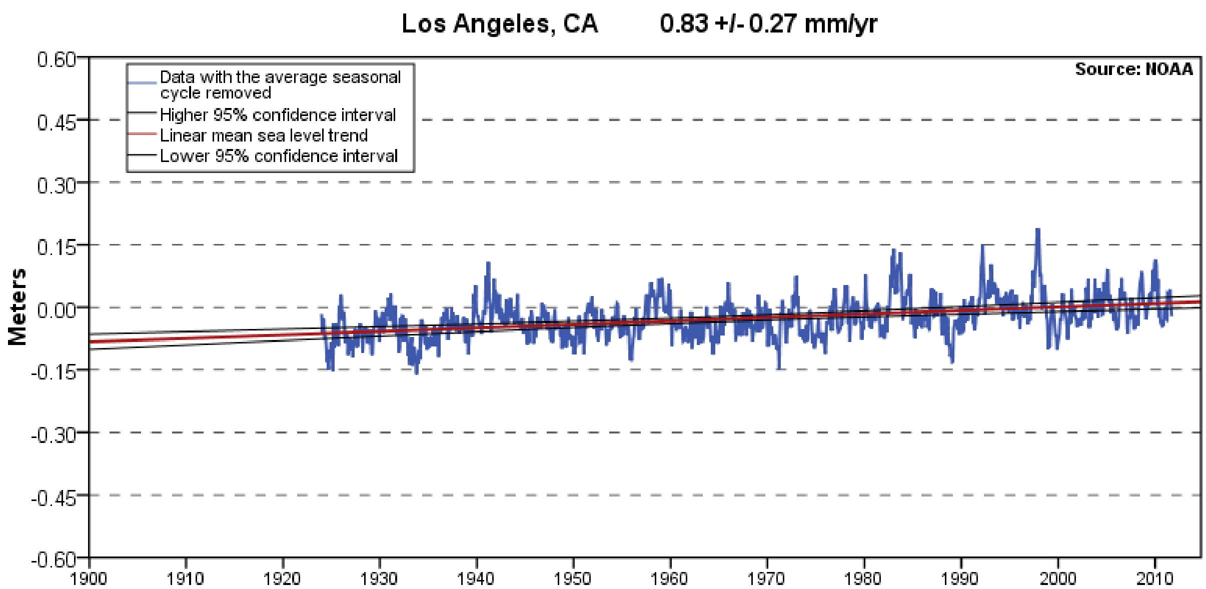
Sea Level Rise

World scientists and science institutes have a clear consensus that accelerating global climate changes are occurring. Evidence includes: increasing concentrations of carbon dioxide (CO_2) and other “greenhouse gases (GHGs)” in the atmosphere; rising average global air temperature and average ocean surface temperatures (which affect extreme weather); substantial reduction in the thickness of arctic ice sheets; and rising average sea levels (Intergovernmental Panel on Climate Change [IPCC] 2013). These changes are destabilizing climate processes, and are forecasted to create increasingly serious effects worldwide. There is also scientific consensus that these accelerated climate changes result from increasing worldwide amounts of GHGs, including CO_2, emitted into the atmosphere by human activities. These gases act like a greenhouse to trap heat in the earth’s atmosphere. They absorb radiation and release it as heat to maintain the temperature of the planet. But the balance of gases in the atmosphere is upset, and the increased GHG content causes excess heat to be retained. Past weather patterns of heating and cooling, over thousands of years, have involved atmospheric CO_2 levels ranging between 180 and 280 parts per million (ppm). The CO_2 level has increased to more than 380 ppm within just a few hundred years and continues to increase rapidly relative to historic patterns (IPCC 2013).

One of the effects of this global warming is SLR, resulting from the melting of ice caps and expansion of the water column through heating. The IPCC (2013) documented an increase in Mean Sea Level (MSL) of between 4 and 10 inches over the preceding 100 years and has predicted that sea level could rise between 7 and 23 inches over the next 100 years. The State of California has incorporated these rates of SLR into policymaking processes for purposes of calculating the potential impact of SLR on proposed coastal development (California Coastal Commission [CCC] 2013).

At a given coastal site, the rate of global SLR is of less practical importance than the local rate of SLR relative to shore. This rate is known as the *relative SLR rate* and is the net sum of the global SLR rate with addition or subtraction of local land uplift or subsidence. SLR rates at a specific location can also be influenced by shorter time-scale climatological effects such as ENSO and the PDO. In the Los Angeles area, long-term tide records (1924 to present) at the National Oceanic and Atmospheric (NOAA) Los Angeles Outer Harbor station show a water level change of 3.3 ±1.1 inches per century (see Figure 3.1-3). This is significantly less than (half) the historic average global SLR rate of 6.6 ±2 inches per century (IPCC 2013); land uplift at this location may account for the difference (3.3 inches per century). Recent State projections for the Los Angeles region identify a SLR of approximately 5.8 inches by 2030 (within a range of 1.8 to 11.8 inches), 11.2 inches by 2050 (within a range of 5.0 to 23.9), and 36.7 inches by 2100 (within a range of 17.4 to 65.6 inches) (CCC 2013, National Research Council [NRC] 2012). As global climate change progresses and the overall level of the ocean rises, increased erosion rates will further reduce public access to the public trust lands along the beach and alter beach and rocky intertidal habitats.

Figure 3.1-3. Sea Level Rise at Los Angeles Outer Harbor Buoy



SLR will likely affect public trust resources along Broad Beach through changes in sea level elevation, storm intensity and frequency, and wave direction and height. Such changes could exacerbate coastal erosion rates, which could reduce the amount of beach accessible to the public and lead to changes in intertidal and subtidal marine habitats. Past beach erosion and landward advances of the mean high tide line (MHTL) have resulted in increased areas of rocky intertidal habitats and reduced the amount of beach accessible to the public to the point where usable beach is only accessible during low tide. For example, during a modest medium tide of approximately +1.5 feet on April 7, 2014, ocean levels reached the emergency revetment that was installed in 2010, with only limited pockets of beach along the entire 4,100 feet of revetment, substantially interfering with lateral access and leaving little room for recreation (AMEC 2014). Conversely, based on a review of past beach profiles, the area of rocky intertidal habitat exposed at low tides appears to have substantially increased in comparison to sandy beach habitat. This rocky habitat remains submerged for long periods of time as most of intertidal beach is covered by even modest tides.

Water Levels

Tides, storm surges, and ENSO events influence water levels, potentially generating elevated water levels that contribute to coastal-related flooding and damage. Tidal fluctuations are superimposed on sea level. The tide is predictable and can be disaggregated into a set of constituent frequencies near one and two cycles per day, each having a given amplitude and phase at any location. Substantial fluctuations in the range of the tide occur at two cycles per month (spring and neap), two cycles per year, every 4.4 years, and every 18.6 years (tidal epoch).

The tides at the Broad Beach area are classified as mixed semidiurnal (two unequal highs and lows per day). Tide characteristics from the tide gage nearest the Broad Beach area (NOAA's Los Angeles Outer Harbor Tide Station) are shown in Table 3.1-1. Water levels and elevations on land are referenced to the MLLW datum for the 1983-2001 tidal epoch.

Table 3.1-1. Water Levels at Broad Beach Based on NOAA's Los Angeles Outer Harbor Tide Station

Water Level	Elevation to MLLW Vertical Datum
Extreme High (Observed January 10, 2005)	+7.9 feet
Mean Higher High Water (MHHW)	+5.5 feet
Mean High Water (MHW)	+4.7 feet
Mean Sea Level (MSL), 1983-2001 Epoch	+2.8 feet
National Geodetic Vertical Datum -1929 (NGVD29)	+2.6 feet
Mean Low Water (MLW)	+0.9 feet
North American Vertical Datum – 1988 (NAVD88)	+0.2 feet
Mean Lower Low Water (MLLW)	0.0 feet
Extreme Low (Observed December 17, 1933)	-2.7 feet

Source: NOAA/NOS 2008. Water elevation records were available from 1923 to 2011

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 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 6 feet. The extreme observed high tide is about 7.9 feet above MLLW and the extreme low is 2.7 feet below MLLW. The mean sea level is about 2.8 feet (1983-2001 Epoch). Seasonal sea level at the Broad Beach area, 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).

In Southern California, the highest tides of the year typically occur in the winter months. Wave overtopping and wave-related coastal damage often occurs when an extremely high tide coincides with high storm waves. A statistical analysis of extreme water elevations was developed based on recorded annual extreme high water elevations obtained from NOAA's Los Angeles Outer Harbor reference tide station. Water elevation records were available from 1923 to 2002. Table 3.1-2 shows the annual extreme high water elevation versus recurrence interval. The extreme still water levels combined with SLR projections provide the basis for estimating a design water level for coastal engineering analyses.

Table 3.1-2. Extreme Water Levels versus Recurrence Interval

Recurrence Interval (Years)	Extreme Still Water Elevation (Feet, MLLW)
5	7.4
10	7.6
25	7.7
50	7.9
100	8.0

Source: NOAA Los Angeles Outer Harbor reference tide station data

Storm surges, which result from the effects of lower atmospheric pressure and higher wind speeds during storms, increase the water level above the tide. Together, tides, storm surges, and sea level 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 1982-1983, 1997-1998, and 2009-2010), large waves can be far more effective in causing flooding, structural damage, beach erosion, and cliff failure than under normal conditions. The typical storm-surge component of sea level can raise water levels a maximum of 1 foot above the tide.

Shoreline Position (Historic to 2010)

Almost all beaches are permanent features (at least over 100- to 1,000-year periods) in that they do not vanish, but experience cycles of expansion and contraction on many time scales (Everts Coastal 2009). Annual oscillations in beach size are well recognized in California. Contraction due to offshore transport happens during fall and winter storms; expansion follows in the spring and summer as sand returns landward when the wave climate is more benign. Long-term oscillations in beach size can be related to climatic events such El Niño or La Niña which may affect wave height, frequency, and direction, with associated impacts on rates and direction of sand transport. Rainfall intensity can also affect sediment input into the system. Natural events such as major wildfires, particularly when followed by heavy rains, can lead to major pulses of sediment into the littoral system with substantial changes in beach width. Changes in a beach's sediment budget through interruption of natural longshore transport, such as harbor or seawall, can also impact long-term beach width.

Beaches in the Zuma Littoral Subcell, including the Broad Beach area, appear to have experienced major oscillations in historic width over extended periods. Much of the

Zuma Littoral Subcell, including all of Broad Beach, is backed by an inactive sea cliff, with Broad Beach Road and the existing homes built on active dunes and back beach areas located at the toe of this formerly active sea cliff. This once-active feature: (1) exhibits clear evidence of past wave attack at its base and indicates the beach was much further landward of its present location sometime well before 1870; and (2) indicates that the active coastal process zone was (on average) nearly 300 feet landward of its present position, with potentially one or more intermediate headlands between Lechuza Point and Point Dume (Everts Coastal 2009).

Broad Beach has also been much wider, extending seaward from its current shoreline position by more than 100 to 200 feet. Broad Beach was a relatively wide beach from the late 1960s into the 1980s, a time period that corresponded with construction of many of the existing homes. Broad Beach reached a peak width in 1970 with a yearly average of 60 feet landward of the existing MHTL, although the beach has been receding since this time. Between 1974 and 2009, approximately 600,000 cy of sand has been lost at Broad Beach, a majority of which moved east to nourish Zuma Beach and other locations down coast (Everts Coastal 2009). The shoreline moved landward an average of 65 feet during that time period. The area of greatest beach erosion occurred close to Lechuza Point and tapered off toward Trancas Creek. Since the sand budget became negative around 1974, the Broad Beach sand loss rate has accelerated to approximately 35,000 cy/yr between 2004 and 2009 (Everts Coastal 2009) and further increased to 45,000 cy/yr between 2009 and 2012 (Everts Coastal 2014).

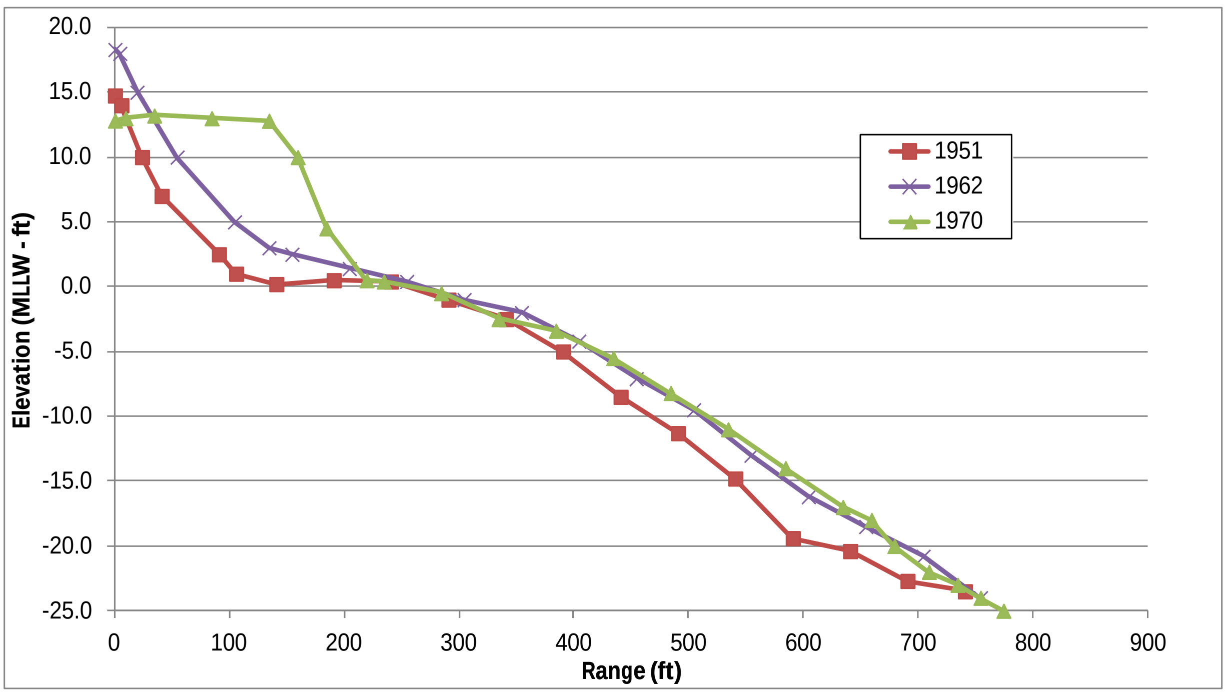
Although beach volumetric data show four minor recoveries in beach width over the last 40 years, several recent studies of the coastal region encompassing Broad Beach have identified a trend of continued erosion without major recovery in beach width since the early 1970s. The beach is narrowing due to a negative sand balance caused by a reduction in sand supply entering around Lechuza Point, and/or an increase in sand loss due to a change in the magnitude and/or direction of the wave energy that transports sand from Broad Beach. Studies conclude that this trend of erosion appears to have accelerated in the last two decades. Recent El Niño storm seasons have exacerbated the shoreline recession resulting in structural damage and further beach erosion.

The 1997-1998 El Niño storms caused considerable shoreline erosion and related storm wave damage along the California coastline. Many Broad Beach homes were threatened, causing many homeowners to construct temporary sand bag revetments to protect residential structures and leach fields. One residence suffered major structural damage, which resulted in its complete destruction. During one particularly severe storm in early February 1998, with sand bags already in place, the active beach scarp retreated more than 30 feet in the course of two days (TerraCosta, 2008). The 2007-2008 winter season, though milder than the 1997-1998 winter, also resulted in significant retreat of the beach. In December 2009, a significant narrowing of the beach occurred due to storm wave attack resulting in widespread failure of the existing temporary emergency sand bag revetments, especially at the west end of the beach. Waves and higher tides eroded portions of the historically wide dunes along the east end of Broad Beach as well.

Historic Beach Profile and Shoreline Measurements

Historic beach profile surveys carried out in 1951, 1962, and 1970 show severe erosion at the inshore and offshore part of the profile (see Figure 3.1-4). 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. Broad Beach at its widest configuration had a berm height of 12 feet above MLLW and a beach face slope of 1:6 (8 degrees). Broad Beach has a steep beach face slope, indicating that the sand grain size is coarse.

Figure 3.1-4. Historic Beach Profile Comparison (near 30870 Broad Beach Rd.)

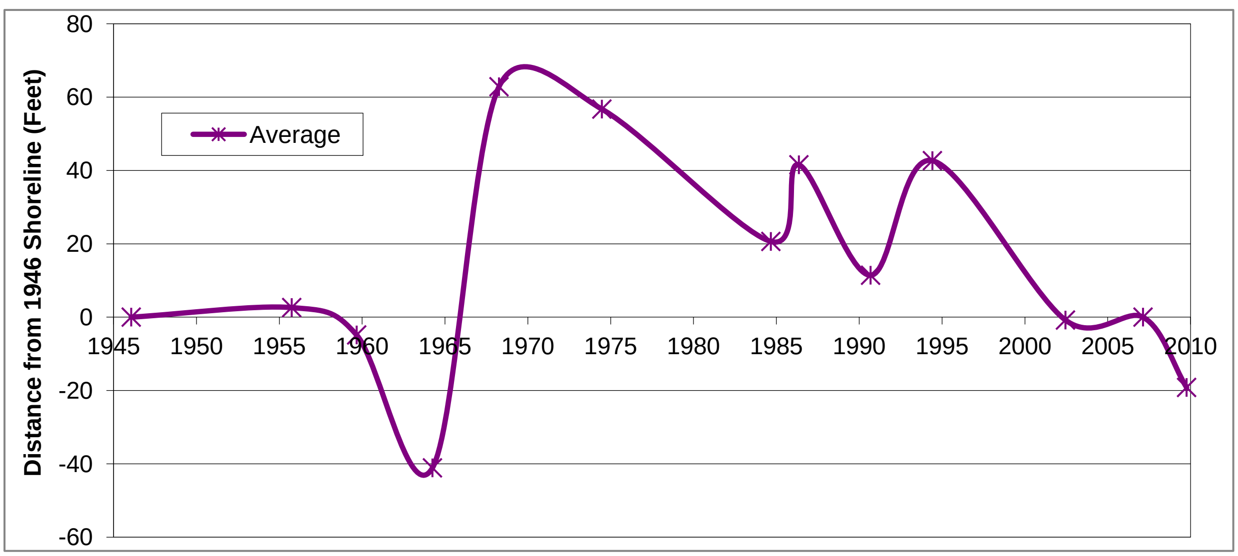


As part of a study of the California coast, the U.S. Geological Survey (USGS) developed estimates of short-term and long-term historical shoreline change for the Santa Monica Region, which includes the Broad Beach area (USGS 2006). This study evaluated shoreline trends by comparing three historical shorelines digitized to represent general shoreline position in the 1800s, 1920s-1930s, 1950s-1970s, and a recent (1998-2002) shoreline position determined using optical remote sensing technology. Long-term rates of shoreline change were calculated using all four shorelines; short-term rates were developed by comparing the two most recent shorelines. Within the Santa Monica region, Leo Carrillo Beach upcoast of Broad Beach had the highest rate of long-term erosion at -0.3 meters per year (m/yr). The maximum short-term (1998-2002) shoreline change rate of -2.2 m/yr occurred at Trancas Beach, the eastern end of Broad beach.

The technical study by Moffatt & Nichol (2012) addressed beach width changes at Broad Beach using shoreline positions extracted from historic aerial images of beaches gathered from various sources. 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 study calculated average changes in beach width, seasonal beach width change rates, and historical minimum and maximum beach widths. Estimates of volumetric changes were computed based on beach profile changes between two dates.

The study included an analysis of shoreline changes at Broad Beach from 1946 to the present, relative to the 1946 shoreline that was chosen as a reference point (distance from 1946 shoreline at 1946 is 0). Analysis of the average shoreline change across Broad Beach revealed a significant increase in the shoreline through the late 1960s, followed by significant reductions from 1970 to 2010. The average shoreline relative to 1946 is depicted in Figure 3.1-5.

Figure 3.1-5. Average Shoreline Change Relative to 1946: Broad Beach

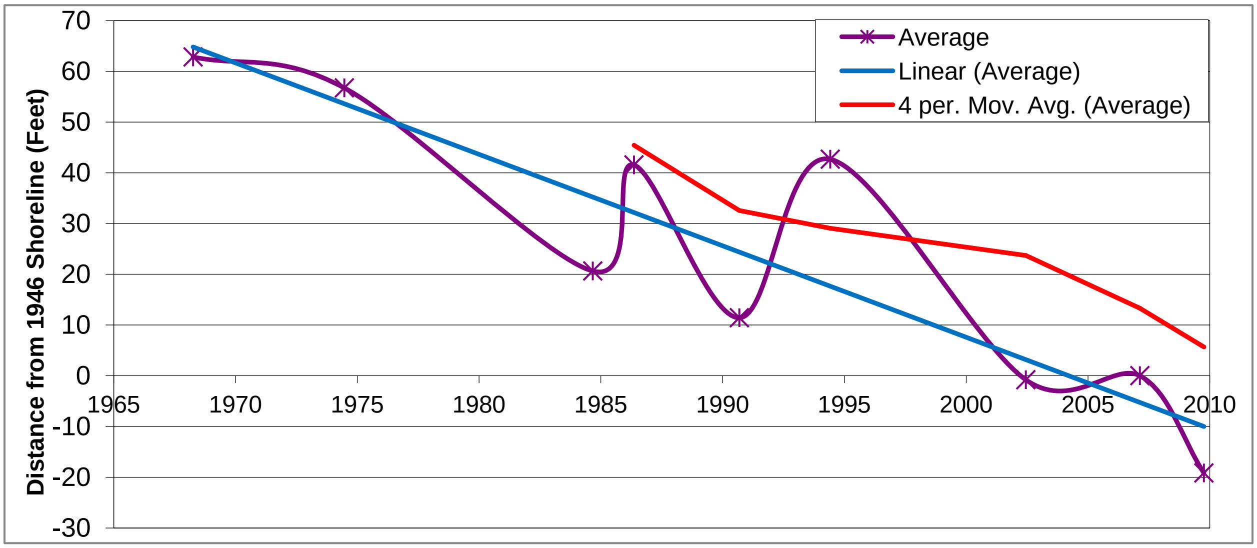


The plot of the distance from the 1946 shoreline (purple line) reveals that:

1) average beach width has varied significantly since 1946;
2) the beach at Broad Beach was at its widest 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.

Moffatt & Nichol noted that the position of the beach in 2009 is within 20 feet of its position in 1946, but the majority of the beach had been artificially prevented from retreating in 2009. To further analyze the loss of shoreline from 1970 to 2010, Moffatt & Nichol plotted the linear regression to determine the average loss over the entire period, and the moving average to determine whether the rate of change has been increasing. These plots are shown in Figure 3.1-6.

Figure 3.1-6. Average Shoreline Change for Broad Beach



The linear regression (blue line) indicates that the beach has lost width at an average rate of about 2 feet per year since 1970. The moving average line (red line) indicates that the shoreline recession has been happening at a variable rate, but appears to accelerate in the 2000s. Moffatt & Nichol also included an analysis of the shoreline change for four separate sections of Broad Beach. The four sections of Broad Beach that were considered are defined as Beach Bins 2, 3, 4, and 5. Definitions and descriptions for each of these sections are provided in Table 3.1-3. Analysis of the four beach bins revealed similar trends across the various bins, but significantly different magnitudes of change between the west end and the east end of Broad beach. These results are presented in Figure 3.1-7.

All four beach bins experienced significant increases in the shoreline for all beach bins through the late 1960s, reaching their peaks around 1970; however, from 1970 to 2010 there were significant reductions in the shoreline in Bins 2 (blue line), 3 (green line), and 4 (red line), and moderate reductions in the shoreline in Beach Bin 5 (orange line). Bin 2 represents the westernmost portion of Broad Beach near Point Lechuza, and Bin 5 represents the easternmost portion of Broad Beach near Trancas Creek. A comparison of these curves indicates that Bin 2 (West Broad Beach) eroded more quickly than Bin 3-5 and that the eroded sand is being transported to the downdrift (eastern) beaches.

Table 3.1-3. Description of the Four Beach Bins of Broad Beach

Bin		Beach Description	Length (feet)	Distance from Point Lechuza (feet [miles])
	**2**	West Broad Beach_1	1,420	1,420 [0.3]
	3	West Broad Beach_2	1,500	2,920 [0.6]
	4	East Broad Beach_1	1,450	4,370 [0.8]
	5	East Broad Beach_2	1,945	6,315 [1.2]

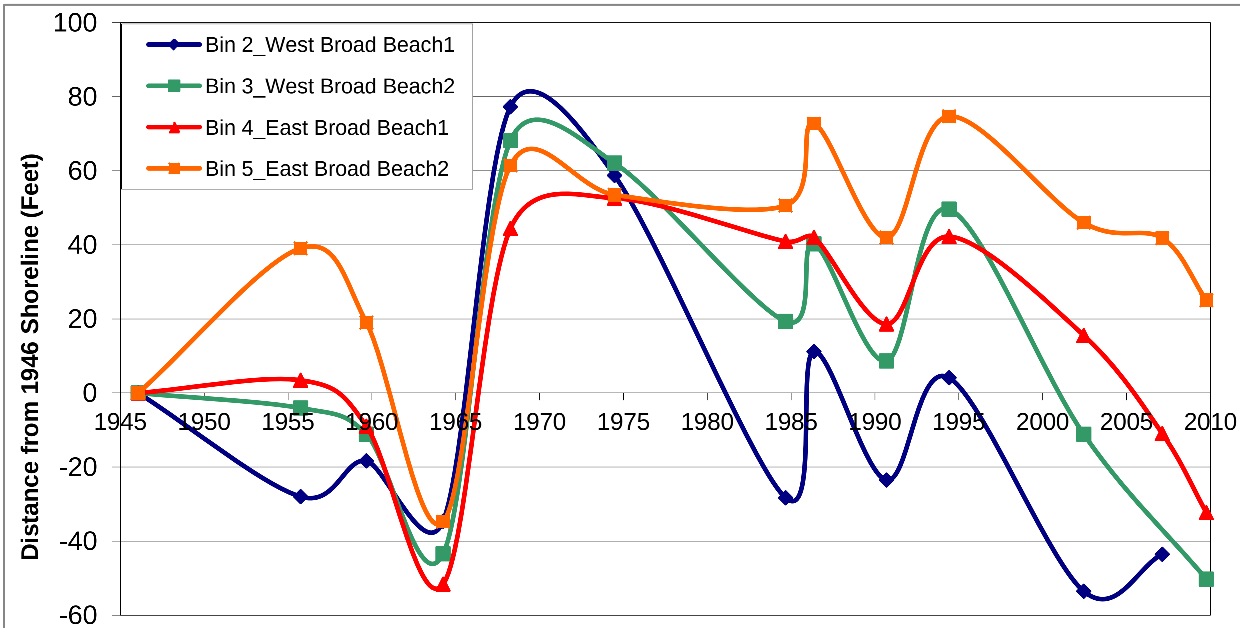


Figure 3.1-7. Shoreline Change Relative to 1946: Bins 2-5

Sediment Transport Measurements

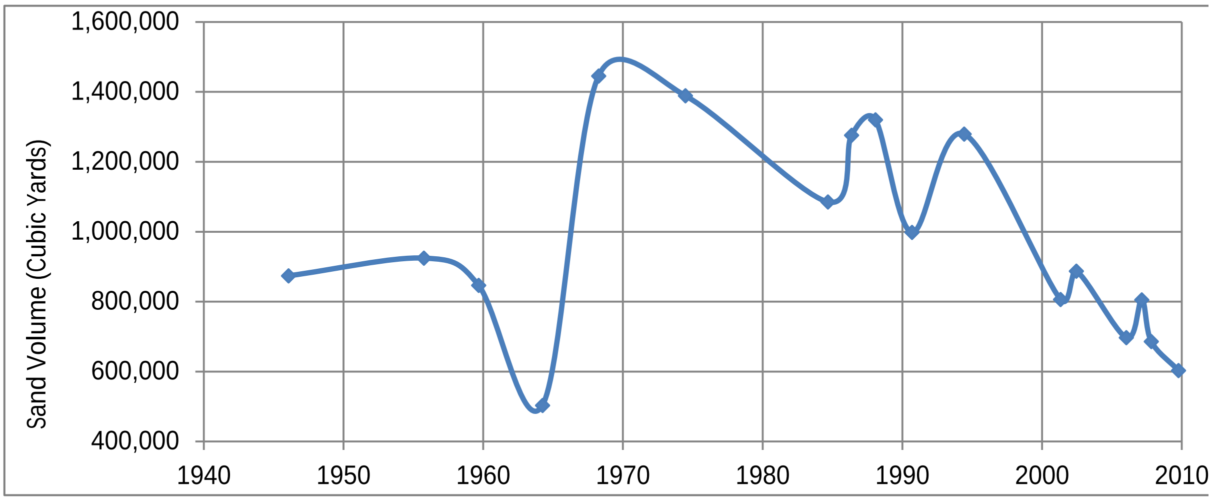
Moffatt & Nichol (2013) measured sediment transport, or the gain and loss of sand, from Broad Beach based on average shoreline measurements. According to this analysis of average beach volumes at Broad Beach, the earliest switch from rise to fall in volume appears to have occurred in the late 1960s and 1970s. Although four recoveries in beach sand volume have occurred since peak beach width around 1970, none matched or surpassed the previous peak beach width from around 1970; rather, each was smaller than the former and was followed by a progressive loss of sediment to the present (Figure 3.1-8). The study also analyzed sediment transport trends at Broad Beach across various periods and their associated sand loss rates in cy/yr. These trends indicate a continuing pattern of erosion since the 1970s, and suggest the trend of sand volume loss along Broad Beach has recently accelerated. These findings are presented in Table 3.1-4.

Table 3.1-4. Sand Loss Rate from Broad Beach

Period	Years of Data	Loss Rate (cy/yr)
1968-2009	41	20,000
1986-2009	23	28,000
2001-2009	8	26,000
2006-2009	3	35,000

Source: Moffatt & Nichol 2013. Estimates were based on analyses of historic shoreline positions.

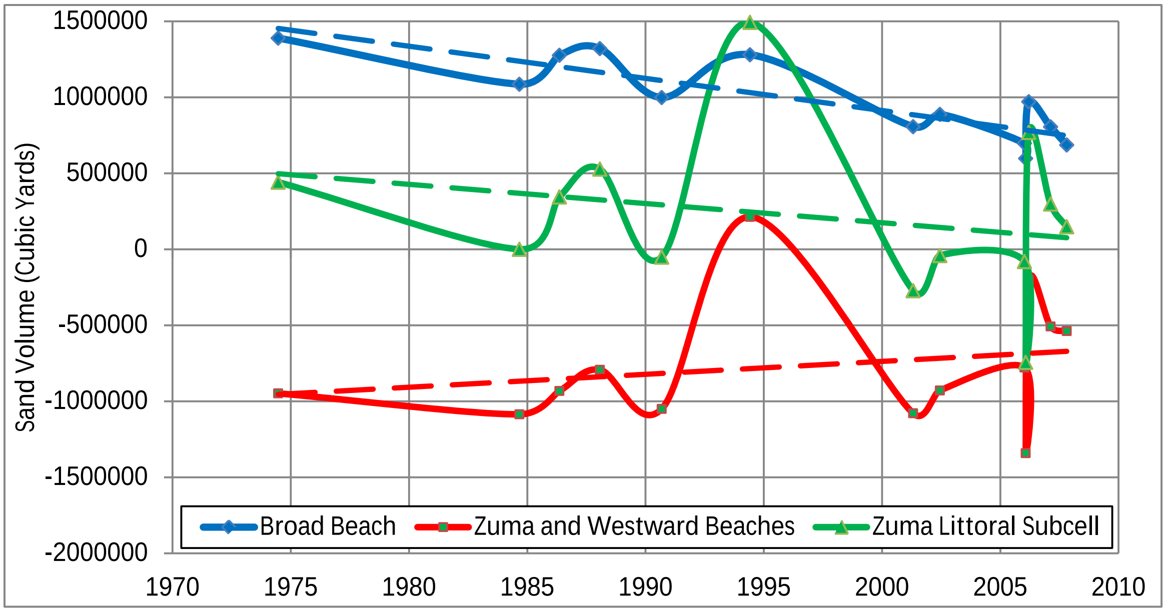
Figure 3.1-8. Volumetric Changes of Sand at Broad Beach



Sand lost from Broad Beach is carried either offshore or down coast. Therefore, a comparison of the historical behavior of Broad Beach with the rest of the Zuma Littoral Subcell provides useful information on the evolution of Broad Beach within the larger context of the hook-shaped bay that includes Broad Beach at its western end. This comparison may help to identify potential causes of the Broad Beach retreat, since changes in one location of a hook-shaped bay tend to correspond with changes elsewhere in the bay.

Broad Beach experienced very different trends in sediment transport through the study period than Zuma Beach and Point Dume State Beach (Westward Beaches). The volume of sand at Broad Beach increased until about 1970, and then began a decline that continues to the present. In contrast, Zuma Beach and Point Dume State Beach experienced a net accretion over the same 60-plus year interval. The large reversal to sand loss in the 1970s at Broad Beach is not evident in the two beaches down coast, suggesting the hooked bay is rotating as its shoreline retreats in the west and advances in the east. A graphical comparison of the volumetric changes in sand at Broad Beach, the combination of Zuma Beach and Point Dume State Beach (referred to as "Westward Beaches" in the figure), and the Zuma Littoral Subcell are shown in Figure 3.1-9.

Figure 3.1-9. Sand Volume Comparison (Broad Beach—Western Beaches)



The trendlines for this analysis indicate that between 1974 and late 2007, Broad Beach losses (blue line) averaged over 21,000 cy/yr of sand. During this same time period, Zuma Beach and Point Dume State Beach (red line) exhibited an average annual accretion of about 8,500 cy/yr. The combined net loss in the Zuma Littoral Subcell between 1974 and 2007 was about 12,500 cy/yr. Although eastern beaches of the Zuma Littoral Subcell have been receiving sand over the last 60 years, the Subcell has been losing sand overall and the point of sand loss versus gain has been shifting eastward. This trend is depicted in Figure 3.1-10, which shows the volumetric rate of change at Broad Beach, Zuma Beach, and Point Dume State Beach over three different time periods.

Figure 3.1-10. Volumetric Changes Along the Zuma Littoral Subcell

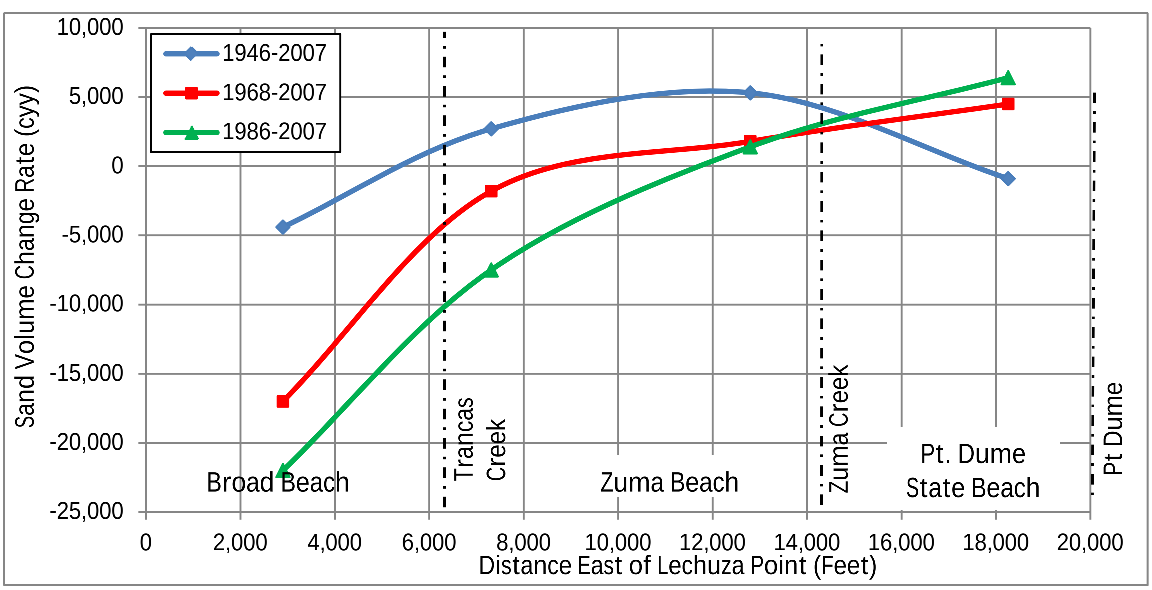


Figure 3.1-10 illustrates an increasing rate of sand loss at the Lechuza Point end of the Zuma Littoral Subcell, and a declining rate of sand loss or sand gain, from west to east in the western two-thirds of the Subcell. The rate of sand gain in the eastern third of the Subcell increased with time. The cross-over point (where sand loss turns to gain) progressively moved eastward with time (about 5,000 feet east of Lechuza Point from 1946 to 2007; about 8,000 feet east of Lechuza Point from 1968 to 2007; and about 12,000 feet east of Lechuza Point from 1986 to 2007). This evidence suggests that the beach retreat problem has spread to the west end of Zuma Beach and is progressing eastward toward Point Dume State Beach. Zuma Beach also appears to have experienced substantial narrowing from historic width during the winter of 2013-2014 compared to 2012-2013, perhaps reflective of the major storm waves of March 2, 2014.

Geologic and Tectonic Setting

The Southern California Coast is a complex, tectonically active region and is characterized as a collision coast wherein the Pacific Ocean plate subducts, or is pushed downward by the North American plate. This process manifests in the form of narrow offshore shelves cut by submarine canyons, with uplifted marine terrace and coastal mountains. Broad Beach lies atop a buried wave-cut terrace etched upon rocks of the Trancas Formation ($F^{\underline{M}}$) (Dibblee and Ehrenspeck 1993). It is comprised of medium-grained beach sand and finer-grained dune sand, both of Holocene-age (Dibblee and Ehrenspeck 1993). The modified surface of the beach and dune sands exists at elevations ranging from mean sea level (MSL) to approximately 15 feet above MSL. The beach is nestled against a wave-cut cliff that exposes fine- to coarse-grained alluvial deposits of Pleistocene age (Dibblee and Ehrenspeck 1993). The modified toe of this cliff is at an average elevation of 35 feet MSL. The top of the cliff represents a man-made surface cut into the older alluvium for placement of PCH.

The southeast end of Broad Beach is separated from Zuma Beach by fluvial deposits derived from Trancas Creek. Holocene age alluvium is deposited at the mouth of Trancas Creek, forming a low mound at the interface with the beach sand. This mound is formed by wave action pushing sand back up into the mouth of Trancas Creek, combined with overlying dune sand. Low levels of surface flow from Trancas Creek generally pond landward of this mound most of the year in Trancas Lagoon. Surface freshwater flows change to subsurface groundwater flows beneath the alluvium/beach sand mound to discharge into the sea. During the rainy season, higher surface flows in Trancas Creek tend to breach the mound and discharge directly into the ocean. Additional discussion of Trancas Lagoon can also be found in Section 3.5, *Marine Water and Sediment Quality.*

Broad Beach is not shown as affected by faulting (Jennings 1975, 1977, 1992, 1994, Jennings and Bryant 2010, Jennings et al. 2010, Dibblee and Ehrenspeck 1993, Jennings and Strand 1969, Bryant 2005, Frankel et al. 2002, USGS 2002, 2006, 2007, 2008, Los Angeles County 1990, 2008, and Malibu 1995). The area does not lie within an Alquist-Priolo Earthquake Fault Zone as defined by the State of California (Bryant and Hart 2007). The area also does not lie within a county or city Fault Hazard Zone (Los Angeles 1990, 2008, and Malibu 1995). The maximum magnitude earthquake (M_{MAX}) of faults in the Broad Beach area is determined from measurements made by the USGS (2008), Southern California Earthquake Center (2010), and Cao et al. (2003).

The Malibu Coast reverse fault lies 1,300 feet north of Broad Beach (Jennings and Strand 1969, Dibblee and Ehrenspeck 1993). The fault generally marks the break in slope along the toe of the Santa Monica Mountains, with the mountains experiencing uplift along the fault. The Santa Monica reverse fault is shown as the eastern extension of the Malibu Coast reverse fault (Jennings and Strand 1969). The city of Malibu (1995) showed the Escondido thrust fault, which lies approximately 2,000 feet northeast of Broad Beach, as offsetting rocks of Miocene age, but the city did not show the Escondido fault on the general plan fault map (City of Malibu 1995). The state of activity of the fault is not known. The eastern portion of the Escondido fault, as shown by Malibu (1995), was mapped as the Ramirez thrust fault, the western end of which is located approximately 0.5 mile southeast of Broad Beach (Dibblee and Ehrenspeck 1993). Dibblee and Ehrenspeck (1993) showed the Ramirez fault offsetting rocks of Miocene age, but as buried beneath sediments of Pleistocene age. The Ramirez fault does not appear to represent an active fault as defined by the Alquist-Priolo Act.

The Anacapa-Dume reverse fault lies off the coast approximately 6 miles south of Broad Beach (Veddar et al. 1986, Bryant 2005). Pinter (2010) considered the Anacapa-Dume fault and the Santa Cruz Island fault as primarily left-lateral faults with minor reverse components. The Anacapa-Dume fault, which marks the break in slope between the submarine slope of the Santa Monica Mountains and the floor of the San Pedro Basin, continues to the west as the Santa Cruz Island fault (Veddar et al. 1986). The Anacapa-Dume fault zone displays a slip rate of about 3 millimeter/yr (mm/yr) and is considered to be capable of generating an M_{MAX} earthquake of momentum magnitude (M_W) 7.2 (USGS 2008). The Santa Cruz Island fault is listed as capable of an M_{MAX} earthquake of M_W 7.2, with a slip rate of around 1 mm/yr (USGS 2008).

Veddar et al. (1986) showed the northwest end of the Palos Verdes fault located about 10 miles southeast of Broad Beach. The Palos Verdes fault displays evidence for both right-lateral strike slip and reverse slip movement (Fischer et al. 1987, Dibblee 1999). The Palos Verdes Hills are thought to have been uplifted by movement along the Palos Verdes fault. However, recognition of the Palos Verdes Anticlinorium reverse fault along the submarine base of the Palos Verdes Hills by Sorlien et al. (2003) appears to provide a better source fault for uplift of the entire Palos Verdes Anticlinorium, as well as the Palos Verdes Hills. The northern end of the Palos Verdes Anticlinorium fault is expected to mimic the length and trend of the higher angle Palos Verdes fault, and, therefore, lies about 10 miles southeast of Broad Beach. The Palos Verdes Anticlinorium fault may also merge with the eastern portion of the Anacapa-Dume fault. The M_{MAX} earthquake of the Palos Verdes fault is provided as M_W 7.3, with an oblique slip rate of around 3 mm/yr (USGS 2008). The M_{MAX} earthquake for the Palos Verdes Anticlinorium fault may be M_W 7.5, but the slip rate is not yet calculated (Sorlien et al. 2003).

Review of digital aerial photography available from Google Earth Pro (Google 2012), World Wind (National Aeronautic and Space Administration [NASA] 2011), and Bing 3D (Microsoft 2011) suggests that several high angle right-lateral strike-slip faults traverse the Broad Beach area. These suspected faults can be traced through alluvial materials of Pleistocene age and older rocks on the photographs. Evidence for these features to represent faulting include offset ridge lines, offset canyons and drainages, aligned canyons, offset landslides, structural control of parallel ridgelines, vertically offset terraces and alluvial fan surfaces, aligned escarpments, and tonal lineaments associated with aligned vegetation. The state of activity of these suspected faults is not known. However, the observed offset of alluvial materials mapped as Pleistocene in age, and offsets observed across landslides considered to be Pleistocene in age, would indicate that these features, if they do represent faults, would be considered potentially active faults using criteria developed by the State (Bryant and Hart 2007).

Liquefaction

The Broad Beach area is included within a potential liquefaction area on the Los Angeles County General Plan (1990) and State Seismic Hazard Zones map (California Division of Mines and Geology 2002). The Malibu General Plan (1995) does not show a map of liquefiable areas. The geologic materials underlying the revetment are mapped as beach and dune sands of Holocene age. These materials are loose and uncemented, as observed at the ground surface during the geologic reconnaissance. Although the thickness of these deposits is not known, these sands are expected to be relatively thin and non-uniformly resting upon dense rock of the Trancas $F^{\underline{M}}$. The depth to groundwater at Broad Beach was not available at the time of this study.

Tsunami

The Los Angeles County General Plan (1990) showed all of Broad Beach located within a Tsunami Inundation Zone. The county's inundation zone is based on a locally generated 100-year earthquake. The State Tsunami Inundation Map for the Point Dume 7.5-minute quadrangle also showed the entire Broad Beach area situated within a Tsunami Inundation Zone (California Geological Survey 2009). The State's Tsunami Inundation Zone is based on an earthquake generated from a distant fault source, like Japan or Alaska, and does not portray the wave run-up anticipated from a locally generated earthquake. The Malibu General Plan indicated that the Broad Beach area could expect tsunami run-up of approximately 5.1 feet during any 100-year period of time and up to 8.7 feet over a period of 500 years. This amount of run-up would be on top of the tidal height at the time of tsunami generation.

3.1.2 Geologic Hazards

In the context of this Project, geological hazards refer to the structural integrity and stability of the existing emergency rock revetment, particularly in relation to geologic processes. Structural integrity is important for long-term protection of public trust resources and values along Broad Beach, and in offshore waters that could be impacted by contamination from septic effluent and other debris from beachfront homes should the revetment fail and homes or septic systems be damaged or destroyed. This Revised APTR describes the variety of existing individual private coastal protection structures at Broad Beach, particularly those at the west end of Broad Beach, but does not include a geotechnical assessment of the stability of these existing individual structures as they are not part of the Project.

Existing Revetment Description

Storm-related erosion in 2008-2009, combined with the threat of the oncoming 2009-2010 El Niño season, prompted the construction of the emergency revetment in 2010. The CCC and city of Malibu approved a temporary emergency revetment as the minimum action necessary to protect Broad Beach, and the least environmentally damaging alternative. The temporary rock revetment design was developed to stabilize the shoreline against further erosion for the 2009-2010 El Niño season.

The emergency revetment has remained in place since its construction in 2010. Since installation of the emergency revetment, the portion of the beach that is seaward of the revetment has continued to erode, with a continued lowering of the beach profile and a loss of remaining dry sand beach berm. Additionally, the 550-foot section at the east end of Broad Beach that is not protected by the revetment and the 100-foot section where there is a gap in the revetment have experienced significant beach losses due to erosion during recent winter storms. During the 2013-2014 storm season the beach and dune system along these sections of Broad Beach eroded approximately 50 to 80 feet landward. Sakrete and sand bag revetments[2] that fronted portions of the dunes protecting the undeveloped lots and six structures on the eastern 550 feet of Broad Beach were largely destroyed by wave action, which lead to substantial landward erosion.

Geological Hazards

The existing revetment extends from 30760 Broad Beach Road, approximately 600 feet west of Trancas Creek, to 31346 Broad Beach Road, just west of the western public access point for Broad Beach and 1,500 feet east of Lechuza Point (Illustration 3.1-4).

[2] Sakrete revetments are fabric bags filled with concrete, often stacked or keyed back into a bluff or dune.

Illustration 3.1-4: *The existing revetment extends for 4,100 feet along Broad Beach fronting the majority of private properties within the area. The majority of the existing emergency revetment is generally comprised of 0.5- to 2-ton boulders, intermingled with smaller rock. The use of such smaller rock could expose the revetment to wear and damage by wave action over the long term.*

Approximately 36,000 tons of rock was used to construct the revetment in 2010. The revetment varies in width from 22 to 38 feet, and rises 12 to 15 feet above MLLW with an average crest elevation of 13 feet above MLLW.[3] Individual boulders for the majority of the revetment are between 0.5 and 2 tons in weight, although many smaller rocks were used during construction. The portion of the revetment between 31302 and 31346 Broad Beach Road was designed to be more robust and incorporated larger boulders (i.e., up to 4 tons per rock). Most of the revetment is on private land. However, portions of the seaward side of the revetment totaling approximately 0.86 acre are located on public trust lands below the Mean High Tide Line (MHTL) as surveyed by CSLC staff in January 2010; an additional 0.73 to 1.04 acre overlies Lateral Access Easements (LAEs) which were granted to the public for lateral coastal access along Broad Beach (see Section 3.2, *Recreation and Public Access*).[4]

Geological Hazard Assessment of the Temporary Revetment

A large earthquake along any of the faults listed above would result in very strong ground motion at Broad Beach. In particular, earthquakes along the nearby Malibu Coast, Anacapa-Dume, or Palos Verde faults would be expected to generate high levels of both horizontal and vertical shaking at Broad Beach. Based on peak ground accelerations measured from the 1971 San Fernando and 1994 Northridge reverse-motion earthquakes, peak accelerations over 1 g (greater than the acceleration due to gravity) should be expected to affect the Broad Beach area at some point in the future.

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[3] The average of the lower low water height of each tidal day observed over the National Tidal Datum Epoch, a 19- year period established by NOAA that currently covers the period from 1983 to 2001.

[4] Disagreement exists between CSLC and the BBGHAD as to location of the MHTL; see Section 2.1.3, *State Sovereign Lands and Private Property Boundary*.

The hydraulic stability of the existing revetments armor stone was evaluated using the Hudson formula outlined in the *Coastal Engineering Manual* (Moffatt & Nichol 2012). This formula is widely used and has many years of successful application on the California coast. Most of the existing revetment was constructed with two layers of armor stone between 0.5 and 3 tons. Based on specified gradation, the median armor stone is between 1 and 2 tons of rough quarry stone with random placement. To meet the 0 to 5 percent damage criteria, the acceptable design wave for the existing revetment is 6 feet for 1-ton stone to 8 feet for 2-ton stone. Depth limited wave heights greater than 6 to 8 feet breaking in front of the existing revetment will likely result in a higher percentage of displacement of boulders and potential damage to the revetment.

The design wave heights calculated for the critical design condition of extreme tides, range from 8.9 to 9.6 feet based on the 2040 SLR scenario. For comparison, the armor stone required to meet the 0 to 5 percent damage criteria for these wave heights is 3 to 4 tons in weight. These results indicate 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 is under-sized and greater than 5 percent damage can be expected under critical design conditions (Moffatt & Nichol 2012). Damage to the revetment from an extreme geologic event of this type does not suggest a complete failure of the revetment. The flexible nature of a stone revetment to shift and settle is one reason it is a 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 (Moffatt & Nichol 2012).

Field inspection by AMEC geotechnical engineers substantiated many of the above-mentioned design assumptions and in-place rock revetment conditions. As reported, the western end of the rock revetment consisted of larger rock stone than that at the eastern end; the team noted a distinctive change in rock size occurred at about 31346 Broad Beach Road (i.e., the western-most beach access point). Thus, the larger stone exists along the western 490 feet (13 percent of the length) and smaller stone exists along the eastern 3,600 feet (87 percent of the length) of the revetment. The use of smaller stone, which was reportedly placed on the interior, was unable to be observed as only the exterior of the wall could be observed.

Overall, the exterior stone appeared to be stable with little evidence of movement having occurred during the 2-year performance period prior to this field inspection (2010 to 2012). In the eastern end where the smaller rock exists, the field survey team noted that individual rock pieces had been separated from the wall and were lying on the beach in front (seaward side) of the wall (Illustration 3.1-5). In these local cases, the wall appeared stable with no obvious perturbations in the overall linear shape of the wall. In these areas the geotechnical field team did not note any deflections in the top of the wall that could indicate settlement of the overall wall. At the western end of the wall where the larger rocks exist, the field survey team did not note any rock pieces that had been detached from the rock mass. The rock sizing indicates relative stability of the rock mass; however, the detached stones suggest that use of a larger size stone would be warranted. Field reconnaissance performed by AMEC staff in 2014 confirmed that the revetment remains intact with little evidence of damage (26 February 2014).

Illustration 3.1-5: *The existing revetment was constructed as an emergency measure using smaller-sized rocks that were not keyed together into bedrock or deeply set into the beach.*

The rock revetment was designed as a trapezoid that is 12 to 15 feet high and about 22 to 38 feet wide at the base. The field team's visual sitings along the top of the revetment indicated that it is approximately level and without significant variations in elevation. These observed conditions agreed with the BBGHAD's "As Built" survey and largely confirmed the placement conditions.

In traversing the beach at the upcoast toe of the rock revetment, the field team noted that the height of the wall (the vertical distance between the top of the wall and exposed toe of the rock) varies from east to west. Overall the height is lowest at the eastern end, on the order of 6 to 10 feet high and greatest at the western end where the height is on the order of 10 to 13 feet high. It is assumed that, as constructed, the top of the wall did not vary in elevation, but that the bottom of the wall rises toward the eastern end. Otherwise, this suggests that beach sand deposition has been greater at the eastern end, and thus, more of the wall has been buried in the process. This observation would be consistent with the known southerly longshore transport direction of sand that occurs along this beach. This observation is significant because wave heights of 6 to 8 feet could overtop the wall at the eastern end and adversely impact structures in this area.

Another issue regarding wall stability is the foundation condition. The rock revetment was placed as an emergency measure on the existing beach surface. This sand material is highly erodible and if the rock is left exposed the rock revetment could be undermined and destabilized. However, the thickness of this sand foundation overlying the Trancas $F^{\underline{M}}$ is approximately 4 feet in depth (Moffatt & Nichol 2012). Because the sand foundation layer is thin, the 15-foot-high revetment wall would still provide protection even if undermining and settlement occurred.

Relationship between Coastal Processes and Public Trust Resources and Values within the Broad Beach Area and Zuma Littoral Subcell

Construction of the emergency revetment in 2010 altered coastal processes at Broad Beach, resulting in changes to wave activity and sand supply in front of the revetment. Proposed beach nourishment, renourishment, and backpassing events may further impact coastal processes. The public's right to use and enjoy public trust resources may also be affected. For example, current use of portions of public trust lands to accommodate the emergency revetment impacts public access, while placement of new sand at the west end of Broad Beach could adversely affect the public's right to enjoy the rocky habitat and reefs in this location; however, creation of a newly widened beach that also covers the revetment would likely enhance access and other trust values.

Broad Beach consists of a narrow beach on its west and central ends, which widens towards the east end and which is backed by residential development. The central 4,100 feet of the beach is backed by the emergency revetment, with various types of private coastal protection structures (e.g., seawalls, timber bulkheads) on 1,500 feet of the west end; and remnant natural dunes, geotextile and Sakrete revetments on the east end. These existing revetments at the east and west ends of the beach are not a part of the Project; however, they aid in protecting septic systems and homes from damage by coastal processes. Broad Beach is rocky toward its west end in the sheltered cove inside of Lechuza Point, then widens and becomes increasingly sandy toward the east, where it terminates at Trancas Creek. Zuma Beach, located within the Zuma Littoral Cell, continues on from Trancas Creek and extends to Point Dume.

The 4,100-foot long rock and sand bag emergency revetment protects 76 of the 109 homes along Broad Beach. A larger-rock revetment design was used along the western 450 feet of revetment due to severity of the erosion, and a more than 100-foot-long break in the continuity of the revetment exists near its east end. The revetment was authorized on a temporary basis until January 25, 2013. The BBGHAD is currently proposing an extension of the life of this revetment as part of the Project.

The eroded shoreline along Broad Beach, combined with the emergency revetment, significantly limits lateral beach access in all areas except for the easternmost few 550 feet. During medium to high tides, most of the beach is submerged with waves that break onto the revetment. Generally the majority of this reach of sand beach is exposed only during low or minus tides, particularly outside of the summer months.

Many homes along the west end of Broad Beach have their base approximately 12 to 20 feet above the water level. Homes on the east end of the beach, which are set back approximately 100 to 125 feet from the beach, are generally 10 feet above water level. Five homes, four undeveloped lots, and the Malibu West Beach Club in the eastern 550 feet of beach are protected only by sand dunes, sand bag revetments, and, in some cases, recently installed Sakrete revetments. Along the western 1,500 feet of Broad

Beach, 33 homes are not protected by the emergency revetment. Substantial erosion of these dunes and damage to the structures occurred over the 2011-2012 and the 2013-2014 storm seasons. In spring of 2014, wave attack and coastal erosion were observed to have eroded these sand dunes at the eastern end of the beach 50 to 100 feet landward of the former sand bag and Sakrete protection revetments, largely destroying these structures and bring the beach to within 30 to 50 feet of these five homes and the beach club. Debris from these revetments litters the surf zone. Homes in the central and west section of the emergency revetment are generally set back from 50 to 100 feet from the revetment, with the closest home only 13 feet landward of the revetment. West of the existing rock revetment, 29 homes exist with varying degrees of permitted and unpermitted shoreline protection (Table 3.1-5).

Table 3.1-5. Western Broad Beach Area Shore Protection Device by Address

Address on Broad Beach Rd.	Revetment	Seawall	Bluff or Piling	City of Malibu CDP Permit Status
31350	No	Yes	No	Permitted
31360	No	No	Yes	--
31364	No	Yes	No	Permitted
31368	No	Yes	No	Permitted
31372	No	Yes	No	Permitted
31376	No	Yes	No	Permitted
31380	Yes	No	No	Permitted
31388	No	Yes	No	Permitted
31406	No	Yes	No	Permitted
31412	Yes	No	No	Not Permitted
31418	Yes	No	No	Not Permitted
31430	No	Yes	No	Permitted
31436	No	Yes	No	Permitted
31438	Yes	No	No	Not Permitted
31444	Yes	No	No	Not Permitted
31450	No	No	Yes	--
31454	No	No	Yes	--
31460	No	No	Yes	--
31500	No	No	Yes	--
31502	No	No	Yes	--
31504	Yes	No	No	Permitted
31506	Yes	No	No	Permitted
31508	Yes	No	No	Permitted
31516	No	No	Yes	--
31520	Yes	No	No	Not Permitted
31528	Yes	No	No	Not Permitted
31532	No	No	Yes	--
31536	No	No	Yes	--
6525	Yes	No	No	Not Permitted
Total	11	9	9	12 Permitted

Source: AMEC 2014. Table is based on CDP information provided for the BBGHAD properties by the CCC and the City of Malibu, 2009-2010, 2009-2010 aerial photos, and title data for BBGHAD properties. The 6525 Point Lechuza Drive property is subject to Lease No. PRC 6470 with the CSLC, but has not been permitted by the City of Malibu.

Existing shoreline protection devices along the west end Broad Beach include rock revetments and sea walls. Of these, 18 homes and an undeveloped parcel in this area have some kind of shoreline protection, varying from massive vertical concrete seawalls and large robust revetments to older timber bulkheads and rock revetment constructed of variable sized armor stone, areas of potentially substandard sized rock (e.g., less than 3 tons). In addition, nine homes have no shoreline protection; six are located on pilings of varying construction from massive concrete pilings to older wooden piers and three overlie unarmored sections of potentially erodible bluff.

3.1.3 Sand Resources

The source of Project sand would be one or more of the following private quarries: CEMEX, Grimes Rock, and P.W. Gillibrand. The Project would require 600,000 cubic yards (cy) of sand to be excavated and transported from the inland source(s) to Broad Beach for use as beach nourishment and dune creation. Sand at all quarries is continually excavated, stockpiled, and removed as part of ongoing quarry and aggregate sales operations. CEMEX and Grimes Rock possess the capacity to provide the full quantity of sand required for the Project, while P.W. Gillibrand can supplement the Project if additional volume is needed. If needed, P.W. Gillibrand has the ability to significantly expand operations to produce sand quantities required for the Project.

The value of sand as a resource for beach nourishment is dependent on sand particle size. Coarse grains are desirable for beach nourishment as they are more consistent with existing beach sand and are also more resistant to wave action and erosion. The mineral composition of the sand is also a factor in creating a sustainable beach profile.

Sand Particle Size and Angularity

Typical grain sizes of sand on Los Angeles County beaches range between 0.1 and 1 millimeter (mm). On Broad Beach the median grain size is 0.25 mm and 0.32 mm above the 0’ MLLW and on the dunes, respectively. The median diameter for inland sand at the quarry sources is larger than what is currently found on Broad Beach. Grimes Rock Quarry sand has a median grain size of 0.40 mm, CEMEX Quarry has a median grain size of 0.85 mm, and P.W. Gillibrand Quarry has a median grain size of 1.0 mm.

The general shape, in terms of roundness, of the sand grains from each sample was visually characterized by using a hand lens magnifier to examine the boundaries of the sand grains and note the angularity and roundness of their edges. The relative roundness of the sand grains was qualitatively compared to diagrams based on the Krumbein (1951) sand grain analysis method, which the shape of sand grains into six different types: Very angular, Angular, Sub-angular, Sub-rounded, Rounded, and Well rounded. Table 3.1-6 provides an assessment of grain angularity on Broad Beach and in the quarry sites. Figure 3.1-11 compares particle angularity quantities by site.

Figure 3.1-11. Sand Particle Comparison between Broad Beach and Source Sites

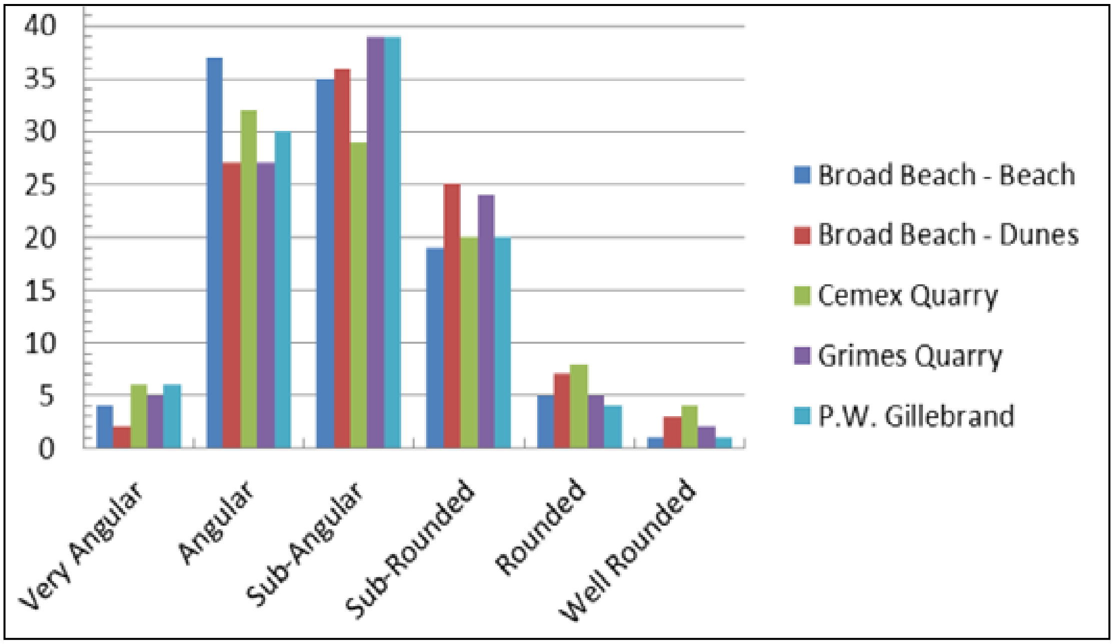

Table 3.1-6. Sand Particle Description for Broad Beach and Quarry Sites

Sample Site	Particle Description
Broad Beach – Beach	Sample is a fine grained sand that is well sorted. It has a generalized color of light gray (Munsell 10YR, 7/1), but individual grains range from very dark (black) to light (white). Individual grains are relatively clean (without coatings) and generally angular to sub-rounded in shape.
Broad Beach – Dunes	Sample is a fine grained sand that is well sorted. It has a generalized color of light gray to very pale brown (Munsell 10YR, 7/2 to 7/3), and individual grains range from very dark (black) to light (white). Individual grains of sand are relatively clean and are generally angular to sub-rounded in shape. There is a slightly higher percentage of rounding in this sample relative to the beach sample, but it is very nominal.
CEMEX Quarry	Sample is a poorly sorted, fine to coarse grained sand. It has a generalized color of very pale brown to light gray (Munsell 10YR, 7/3 to 7/2), but individual grains range from dark (gray) to light (white). The sample in general is angular to sub-rounded. There is a general relationship between the grain size and the roundness: coarse size grains tend to be sub-rounded to rounded; fine to medium size grains tend to be angular to sub-angular. Sand grains have a minor mineral coating. A minor amount of fines (silts/clays) exist in this sample.
Grimes Quarry	Sample is a poorly sorted, fine to coarse grained sand. It has a generalized color of very pale brown to yellow (Munsell 10YR, 7/4 to 7/6), but individual grains range from dark (gray) to light (white). The sample in general is angular to sub-rounded. Unlike the CEMEX Quarry sample there is not a general relationship between the grain size and the roundness, and the coarse size grains. Sand grains have a minor mineral coating. Minor fines content exists in this sample.
P.W. Gillibrand Quarry	Sample is a well-sorted, medium grained sand. It has a generalized color of light gray to white (Munsell 10YR, 7/1 to 8/1), but individual grains range from dark (gray) to light (white). The sample in general is angular to sub-rounded. Individual grains of sand are relatively clean and no significant fines are present in this sample.

Sand Composition

On many beaches, most of the sand (not including seashells) is made of the minerals quartz and feldspar. These grains ultimately came from igneous and metamorphic rocks that are typically very old. Quartz, the most common mineral, is composed of silicon dioxide, while feldspar, the second most common mineral, is made up of sodium, calcium, or potassium combined with silica. Quartz is the most common mineral in many beaches because it is hard, durable, and can survive transport by rivers to the coast and reworking by waves better than other common minerals. Quartz is chemically very stable while other minerals disappear rapidly due to chemical and mechanical destruction before they reach the beach (Pilkey 2011).

Rock and minerals that compose sand on Broad Beach originate in the Santa Monica Mountains and are fed to coastal areas through multiple creeks (Flick 1993 and USACE 2004). The composition of sand from local coastal drainages of the Santa Monica Mountains ranges from basaltic feldspatholithic to quartzofeldspathic (Critelli 2008).

The geologic setting of the proposed quarry sand sources suggests that material mined from this area would be composed of a sandstone sediment source. Large strata of sandstone are typically formed in pre-historic marine environments, suggesting that these materials are former seabed (i.e., marine sedimentary rock) (CEMEX 2013). Sandstone is a clastic (formed from broken or fragmented grains) sedimentary rock most commonly composed of 1/16-2mm sized quartz particles, though it can also contain feldspar, mica, and rock fragments.

3.1.4 Regional Sand Supply Management Efforts

The Project would occur within the context of other ongoing sand management efforts along the California coast. These efforts are described below.

Coastal Sediment Management Workgroup

The California Coastal Sediment Management Workgroup (CSMW), a consortium of State and Federal agencies and non-governmental organizations, is developing and implementing the California Coastal Sediment Master Plan to foster a regional sediment management approach for the entire State. Through this effort, region-specific issues and solutions are coordinated with local/regional partners through Coastal Regional Sediment Management (RSM) Plans designed around littoral cell management. CSMW and its partners have completed four Coastal RSM Plans, and will prepare five more in the near future, using criteria prepared by CSMW as a starting point (Table 3.1-7).

Table 3.1-7. Coastal RSM Plans

Cell	Coastal Segment	CWMW Regional Partner	RSM Plan Status*
Southern Monterey Bay Littoral Cell	Moss Landing south to Point Pinos	Association of Monterey Bay Area Governments (AMBAG)	CSMW's first Coastal RSM Plan completed in November 2008.
Santa Barbara Littoral Cell	Point Conception south to Point Mugu	Beach Erosion Authority for Clean Oceans and Nourishment (BEACON)	Completed in January 2009
San Diego County	Oceanside south to Mexico border	San Diego Association of Governments (SANDAG)	Completed in April 2009.
Orange County	Littoral cells within Orange County	Parks Department, County of Orange	Completed in June 2013
Eureka Littoral Cell	Trinidad Head south to False Cape	Humboldt Bay Harbor Recreation and Conservation District	In preparation.
Los Angeles County	Coastal area within the County	U.S. Army Corps of Engineers, Los Angeles District	August 2012 draft under review
San Francisco Central Bay	Central Bay to Golden Gate Bridge	San Francisco Bay Conservation and Development Commission (BCDC)	BCDC is currently developing a Coastal RSM Plan preparation.
San Francisco Littoral Cell	Golden Gate Bridge to Pacifica	Association of Bay Area Governments (ABAG)	ABAG is currently working to develop a RSM Plan.
Santa Cruz Littoral Cell	Santa Cruz to Moss Landing	U.S. Army Corps of Engineers, San Francisco Region.	CSMW is working to partner with Monterey Bay National Marine Sanctuary to conduct governance and outreach activities.

* CSMW is exploring the possibility of preparing Coastal RSMs for the Morro Bay Littoral Cell (San Luis Obispo County), the Crescent City Littoral Cell (Del Norte County), and littoral cells in Sonoma County.

Los Angeles County

The Los Angeles County coast fronts both the Santa Monica and San Pedro Littoral Cells. The rocky promontory of the Palos Verdes Peninsula and Redondo Canyon interrupts these two littoral cells and inhibits sand transport between them. Broad Beach is within the Santa Monica Littoral Cell. The planning region extends for approximately 74 miles of coastline from Mugu Canyon on the north to the Los Angeles County line. The USACE RSM Plan, completed in August 2012, summarizes the baseline science and relevant physical processes for the area (see Illustration 3.1-6), and identifies challenges and opportunities. Coastal sediment management solution strategies proposed in the RSM Plan for the Malibu region include: establishing an ongoing beach nourishment and erosion control program within the littoral sub-cell at the west end of the reach; removing or relocating improvements in response to the long-term natural shoreline erosion trend; allowing areas of the shoreline which are relatively sediment-limited to exist in a more natural state; and removal of Rindge Dam and economical recovery of trapped sediment behind it for beneficial use (USACE 2012).

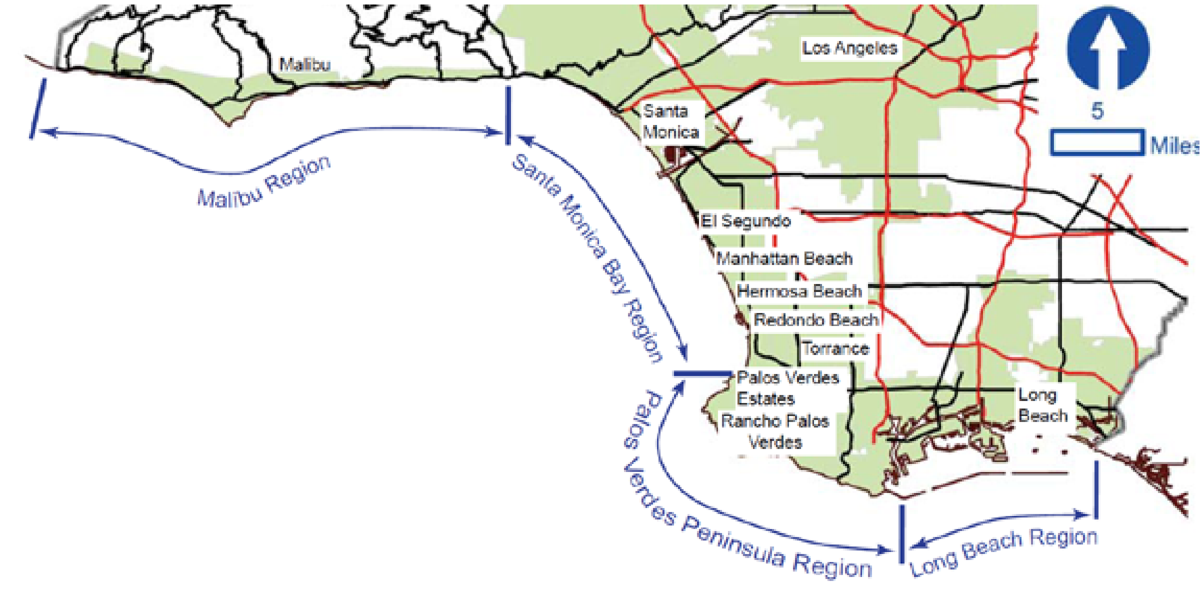

Illustration 3.1-6: *The USACE planning area of the Los Angeles County RSM plan begins west of the Project site at the border between Ventura County and Los Angeles County.*

3.1.5 Regulatory Setting Related to Beach Nourishment, Shoreline Protective Structures, Geologic Hazards, and Sand Use

Statutes related to use of sand for beach nourishment, use of revetments and shoreline armoring, and mining are listed in Table 3.3 in Section 3.0, *Issue Area Analysis*.

3.1.6 Public Trust Impact Criteria

Impacts associated with coastal processes, SLR, and geologic hazards would be considered a major adverse effect if the Project were to result in a:

- Substantial change in wave climate (e.g., wave height, direction, and breaks).
- Disruption of existing surface and subsurface currents and sand transport.
- Substantial change in wave energy and run-up on beaches in the Public Trust Impact Area for the Project.
- Substantial increase in the rate of erosion or reduction in the rate of accretion of beach sand in the Public Trust Impact Area for the Project.
- Change in the ability of coastal protection measures to withstand oceanographic and wave action processes.
- Permanent permitting of an unstable revetment which could result in injury to individuals using the public trust resource.
- Loss of sand as a mineral resource available to naturally nourish coast beaches.

Where applicable, this impact analysis considers the Broad Beach area both in its existing setting, following the 2010 emergency rock and sand bag revetments installation, and in its historical setting without the emergency revetments, characterized by a mix of different types of protective structures, as well as open beach without protective structures at the east end.

3.1.7 Public Trust Impact Analysis

This section describes direct and indirect impacts that may potentially result from the implementation of the Project. Impacts discussed below may occur in the CSLC Lease Area and/or in the Public Trust Impact Area, including down coast beaches.

<u>Historical Coastal Process, Geological Hazards, and Sand Resources Characteristics</u>

Prior to installation of the sand bag revetments in 2008-2009 and the 2010 emergency rock revetment, a variety of coastal protective structures and a segment of open beach without protective structures existed on Broad Beach. Many properties at the west end, beyond where the revetment is located today, had already been constructed on pilings or with timber bulkheads, concrete seawalls, rock revetments, or other protection structures. Most of the properties that are currently protected by the 2010 emergency revetment (from 31346 to 30846 Broad Beach Road) used a variety of individual coastal protection structures, including rock, timber, geotextile, and Sakrete (concrete filled bags) revetments. These individual coastal protection structures were generally not as robust as the 2010 emergency revetment (especially sand bag revetments) and were prone to failure as a result of wave action. In particular, in 2008-2009, homeowners along Broad Beach in the area roughly conterminous with the existing rock revetment installed approximately 4,100 feet of sand bag revetments. Subsequent wave attack on the sand bag revetments installed in 2008-2009, and their failure or threat of failure, was the instigation for installation of the emergency rock revetment in 2010, as there were no robust protective structures along the section of Broad Beach from 30842 Broad Beach Road to the east end of Broad Beach. AMEC field reconnaissance in February 2014 noted that a number of sand bag and Sakrete revetments present in 2012 at the currently unarmored east end of Broad Beach had been washed away and that dunes within this area appeared to have been eroded 50 or more feet landward. Given erosion and loss of beach width at Broad Beach, and the mix of protective structures that were less robust than the existing emergency revetment and the section of open beach along the east end of Broad Beach, the beach and dunes were more susceptible to erosion as a result of coastal processes than they are today.

Geological hazards and sand resources impacts to the public trust resource prior to the construction of the 2010 revetment are consistent with many of the current hazards and resources concerns described above with the exception of the geologic hazards associated with the existing rock revetment. In addition, the sand bag revetments would have been subject to the same situational hazards of being located in the same proximity to existing fault lines and on the same parent and sandy material as the rock revetment. However, the overall integrity of the sand bag revetment would be less than the rock revetment due to the increased mobility and erodibility of sand particles within the sand bags as compared to solid rock boulders. Additionally, an increased liquefaction hazard may have existed for the sand bag revetments resulting in reduced structural integrity in the event of an earthquake.

Projections of Sea Level Rise

The life span of the Project is 20 years and assumes an initial nourishment completion in 2015. In order to estimate potential SLR over the life of the Project, the projected SLR by 2040 was interpolated using linear interpolation based on the NRC's projected SLR for the Los Angeles region by 2030 and 2050 (see Table 3.1-8).

Table 3.1-8. Regional Sea Level Rise Projections for Los Angeles

Year	Projection	Range
2000 to 2030	5.8 inches	1.8 to 11.8 inches
2000 to 2040	8.5 inches	3.4 to 17.9 inches
2000 to 2050	11.2 inches	5.0 to 23.9 inches

Source: Sea Level Rise for 2030 and 2050 are from NRC (2012) (projections interpolated for year 2040), consistent with CCC Draft Sea-Level Rise Policy Guidance, October 2013: www.coastal.ca.gov/climate/slr/guidance/CCC_Draft_SLR_Guidance_PR_10142013_AppxB.pdf, accessed July 2014.

Using linear interpolation results in a slight overestimation of SLR since the models generally predict an exponential increase. However, over the relatively short time period between 2030 and 2050 this provides a reasonable estimate to use for the Project time horizon. Using projections for a 25-year time horizon (2040), the potential range of SLR to be expected at Broad Beach over the Project life ranges from 3.4 to 17.9 inches with a projected value of 8.5 inches.

Longevity of Nourishment at Broad Beach

The longevity of the nourishment at Broad Beach is dependent on a variety of factors, including climatic cycles, wave energy and direction, longshore transport of sand in the littoral cell, sand grain size, other coastal forces and the amount and frequency of backpassing. A variety of methods have been employed to estimate the longevity of beach nourishment (Appendix B). These range from using empirical observations of the rate of historic sand loss from the beach to computer simulations of longshore transport.

The most conservative approach to evaluate nourishment longevity involved using the Generalized Model for Simulating Shoreline Change (GENESIS) numerical model (USACE 1989). The accuracy of the numerical modeling for the shoreline is limited because of the complexity of the coastal processes; however, the GENESIS program has been used in many artificial beach nourishment projects and provides some useful results. Although this model can predict the shoreline reasonably well for Broad Beach, the results should not be used to define a specific shoreline position at a specific date. Rather, the model should be used to predict general long-term shoreline trends. The model results suggest that the rate of beach loss is greatest at the west end of Broad

Beach and the nourished beach may last only 3 to 5 years near Lechuza Point while it may last up to 7 or 8 years at the east end of Broad Beach. However, these model results do not incorporate backpassing events, and identify rates of erosion for 50,000 to 100,000 cy/yr that are as much twice as high as historic erosion rates and so they are particularly conservative.[5]

Although the GENESIS model was not run to consider annual backpassing through the life of the Project, some runs were preformed to assess the benefits of backpassing in the first five years of the Project. The results of these model runs showed that the beach would maintain greater average widths for a longer period with the implementation of backpassing; however, added beach width would be somewhat short-lived at the far west end. Overall, using the worst case GENESIS modeling results, backpassing would prolong the life of the beach nourishment along the majority of Broad Beach by from 1.5 to 7 years, depending on erosion rates, which under worst case GENESIS modeling vary from 50,000 to 100,000 cy/yr. Thus the approximate overall life of beach nourishment under this scenario would range from roughly 11 to 26 years, including the effects of backpassing.

Longevity of the nourishment could also be evaluated by applying an analytical method referred to as the diffusion method. This method takes into account sediment size and breaking wave height. According to this analysis, a 500,000 cy beach nourishment with a median grain size of 0.25 mm (the existing median grain size on Broad Beach) would be expected to last 5 to 8 years. With a larger median grain size of 0.85 mm, the longevity of the nourishment is expected to be 7 to 10 years. Median grain sizes at the proposed sediment sources are 0.47 mm at Grimes Rock Quarry, 0.85 mm at CEMEX Quarry, and 1.00 at P.W. Gillibrand Quarry, so the longevity of the nourishment is expected to be in the 7- to 10-year range, depending on the sand source used. Under this scenario and accounting for one renourishment event, the Project life would range from roughly 13 to 20 years, which may extend to 19 to 28 years with backpassing.

Another approach to estimating longevity of the created beach and dunes is to review historic accelerated erosion rates over the last 2 decades where Broad Beach has been losing an estimated 35,000 to 45,000 cy/yr down coast to Zuma Beach. Under this scenario, assuming 25 percent initial losses of the nourishment sand supply, the 500,000 cy of beach sand would result in the beach lasting anywhere from 8 to 11 years until the dune system would be threatened by erosion and renourishment would be required to sustain the beach and dune systems. With the addition of 450,000 cy of

[5] Backpassing would involve return of an estimated 35,000-50,000 cy/yr of sand from the wider eastern sections of Broad Beach to the narrower western segment of Broad Beach, substantially prolonging the life of nourishment (see Section 2, *Project Description*). However, given progressive erosion of the beach, long-term average backpassing would likely be closer to 25,000 cy/yr (500,000 cy total). Accounting for a worst case post backpassing construction beach loss of 25 percent and variables of wave attack, a total of 375,000 cubic yards may be successfully placed to nourish the upcoast beach.

sand from the renourishment event, total Project life prior to dune erosion and the beginning for potential exposure of the revetment could be 16 to 20 years, with backpassing prolonging beach life by roughly an additional 6 to 8 years for a total Project life of approximately 22 to 28 years under this scenario. Although precise estimates of Project duration are not possible, this scenario is deemed the most likely scenario by both Moffatt & Nichol and Coastal Environments, and is supported by long-term empirical observations of how this beach is performing.

Impact CP/GEO-1: Structural Stability of the Rock and proposed Sand Bag Revetments

The rock revetment is subject to remobilization of boulders along with settling from liquefaction events, and proposed sand bags are subject to collapse, reducing long-term protection of onsite wastewater treatment systems (OWTS) from sea level rise (SLR), and wave action (Major Adverse Effect, Class Mj).

<u>Impact Discussion (CP/GEO-1)</u>

The revetment would serve a critical role as the last line of defense to maintain shoreline protection in the event beach renourishment material is entirely lost to down coast beaches. The revetment essentially protects against uncertainties associated with variability in shoreline change rates due to ongoing beach erosion, and significant short-term beach losses due to large seasonal fluctuations and/or severe erosion due to extreme wave events and potential long-term acceleration of beach erosion due to SLR.

Prior to construction of the revetment in 2010, the narrow beach and dune system were exposed to wave action and subject to erosion and substantial sand loss. The revetment was constructed as an emergency measure, with the majority of the revetment consisting of substandard-sized rocks that were not keyed together into bedrock or set deeply into the beach; the structure is not designed to resist exposure to long-term wave, tidal, SLR, tectonic, or tsunami action. The Project proposes to bury the revetment within the beach nourishment sand sources to reinforce the beach and dune system for between 10 and 20 years.

After the projected loss of the beach and dune systems – in 10 to 20 years depending on erosion rates – the revetment would begin to lose integrity as smaller rocks and boulders are detached from the revetment and scattered by surf action. Such damage may accelerate with SLR, which is projected to reach 5.8 inches by 2030 toward the end of the effective life of the proposed follow-up nourishment event. Liquefaction, seismic settlement, and lateral spreading represent likely impacts to the revetment in the event of an earthquake. A tsunami would overtop and cause severe structural damage to the revetment. Well within the economic life of the homes along Broad Beach (100 years according to Malibu's Local Coastal Program [LCP]), these coastal processes can be expected to lead to deterioration of the revetment to such an extent that high winter surf could break through gaps or overtop lowered sections, damaging septic systems and leach fields, with potentially major adverse effects to water quality This process can be expected to accelerate with SLR. Progressive deterioration of the revetment can be expected to lead to requests for additional emergency authorizations to repair the revetment or to illegal additions to the revetment, creating enforcement issues for property owners and local and State agencies; therefore, adverse impacts resulting from permanently authorizing the revetment despite its relative structural instability would be a major adverse effect.

Subsurface flow derived from the sea is expected to perennially infiltrate the beach sands underlying the revetment. Additional subsurface flow is anticipated to originate from each of the septic systems located immediately landward of the revetment. Sediments underlying the revetment are considered to be highly susceptible to liquefaction and vertical differential settlement in the event that a large earthquake occurs in the vicinity of Broad Beach. The potential for liquefaction and differential seismic settlement to affect the Broad Beach area is substantial.

Lateral spread (i.e., the horizontal movement of near-surface sediment during liquefaction) is also considered to have a high potential for occurrence in the vicinity of the revetment. The unsupported face of the beach sediments along the shore and the seaward-inclined surface of the wave-cut terrace underlying the sands would be expected to enhance the potential for lateral spread to affect the area of the revetment. The potential for lateral spread to affect the Broad Beach area in association with liquefaction is also considered a major adverse impact.

SLR would affect the nourished beach portion of the Project. With beach nourishment under the Project, the average inclination of the proposed beach in the eastern portion of Broad Beach would be 10 horizontal feet to 1 vertical foot (10:1), while the average inclination of the western portion of the beach would be 3 horizontal feet to 1 vertical foot (3:1). Though the overall size of the beach would increase with the nourishment, SLR would result in ocean encroachment onto the newly widened beach, reducing availability of public access over time.

An increase of sea level up to 8.5 inches above current levels with a potential range from 3.4 to 17.9 inches should be anticipated over the 10- to 20-year Project lifespan. Beyond the Project design life, the rates of projected SLR are expected to accelerate and the impacts to Broad Beach will become more significant. A potential acceleration of SLR will subject the revetment to a higher frequency of waves breaking on or close to the structure. This could increase the damage and wave overtopping frequency of the shore protection structure but complete failure of the revetment is unlikely. The most significant impact from a high rate of SLR would be additional maintenance and repair of the structure after a major storm event (Moffatt & Nichol 2012).

A minimum increase in sea level of 3.4 inches vertically over the next 20 years would result in the average encroachment of the sea landward by 10 inches and 3 feet in the western and eastern portions, respectively, of the nourished beach. A maximum increase in sea level of 17.9 inches vertically over the next 20 years would result in the average encroachment of the sea landward by 4.5 feet and 15 feet in the western and eastern portions, respectively, of the nourished beach. Encroachment from SLR partnered with more frequent and more intense storms would subject the revetment to increased stress and destruction over time. Based on best available science and SLR projections provided in the NRC's 2012 Report and the State's Sea-Level Rise Guidance Document, the effects of SLR would compound the overall effects of the other potential geologic hazards along Broad Beach. Additional discussions of SLR and associated impacts can be found in Section 3.2, *Recreation and Public Access*.

The permitting and retention of the rock revetment and/or its reinforcement as reviewed under Alternatives 1, 2, and 6 would not appear to contribute to or exacerbate any geologic impacts associated with the related projects. Replacement of the PCH bridge may reduce potential for seismic damage to this structure, but would not appear to affect or be affected by the revetment. Restoration of Trancas Lagoon may increase the frequency and duration of lagoon mouth breaching, but would also not appear to affect or be affected by the retention and/or reinforcement of the emergency revetment.

Finally, the Project contains a provision to install emergency sand bag revetments along the eastern 550 feet of Broad Beach not protected by the emergency rock revetment. Such sand bag revetments would be installed outside of and fronting the restored dunes only during periods of erosion, such as toward the end of the useful life of either the initial or follow-up nourishment events. Sand bags would offer interim protection during storm events and would generally not be impacted by geologic processes, but would be subject to destruction from wave attack. Their inclusion in the Project would provide periods of short-term protection for the dunes, homes, and OWTS during major events.

Avoidance and Minimization Measure(s)

AMM TBIO-1a (Implementation of a Comprehensive Dune Restoration Plan) would slightly reduce this impact. However, implementation of Alternatives 1, 2, and 6, which include construction of a properly engineered revetment, would improve long-term protection of OWTSs from damage associated with waves and tides and SLR.

Rationale for Avoidance and Minimization Measure(s)

While the emergency revetment is structurally sound on its western end, the emergency revetment is structurally deficient in its central and eastern sections, as it would sustain over 5 percent damage under critical design conditions. Therefore, AMM TBIO-1a is necessary to ensure that the revetment does not become exposed to wave action throughout the life of the Project. Implementation of one of the alternatives that would re-engineer the revetment would reduce this impact to be negligible.

Impact CP/GEO-2: Impact of Coastal Processes on Emergency and Sand Bag Revetments

Over the long-term, after cessation of nourishment and erosion of the beach, substandard construction of the revetment would provide inadequate protection from coastal processes for septic systems, leach fields and homes (Major Adverse Effect, Class Mj).

Impact Discussion (CP/GEO-2)

The emergency revetment is intended to serve as the final defense against shoreline erosion when the beach and dunes are lost to coastal processes. However, based on computer modeling and historic erosion rates, it can be reasonably forecast that the revetment would become exposed as the beach erodes into the dunes in approximately 10 to 20 or more years, exposing the revetment to wave action and coastal processes over the long term after cessation of nourishment activities.

The revetment was constructed as an emergency measure using substandard-sized rocks over most of its reach that were not keyed together into bedrock or deeply into the beach; it is not designed to resist exposure to long-term coastal processes. After the projected loss of the beach and dune systems in 10 to 20 years, the revetment would begin to lose integrity over time as smaller rock and boulders become detached from the revetment and scattered by surf action. Well within the economic life of the homes along Broad Beach (100 years under Malibu's LCP), coastal processes can be expected to lead to deterioration of the revetment to such an extent that high winter surf and design waves could break through gaps or overtop the revetment, damaging septic systems and leach fields, resulting in potential adverse effects to water quality and the public's right to use and enjoyment of public trust resources. This process can be expected to accelerate with SLR, particularly after 2050. Progressive deterioration of the revetment can be expected to lead to requests for additional emergency permits to repair the revetment or to illegal additions to the revetment; thus, impacts related to the structural stability of the revetment would be a major adverse effect.

Sand bag revetments would offer interim protection during storm events and would generally not be impacted by geologic processes, but would be subject to destruction from wave attack. Their inclusion in the project would provide periods of short-term protection for the dunes, homes and OWTS during major events.

Avoidance and Minimization Measure(s)

AMM TBIO-1a (Implementation of a Comprehensive Dune Restoration Plan) would apply and would reduce this impact. Several Project alternatives would improve longer-term protection of septic systems and homes (with potential secondary impacts to public trust resources) from damage associated with waves and tides and to a lesser extent SLR. These would include Alternatives 1, 2, and 6 (see Section 4.0, *Alternatives*).

Rationale for Avoidance and Minimization Measure(s)

Implementation of a comprehensive dune restoration plan through continued nourishment and protection of the dune system would function to reduce impacts to existing septic systems from coastal processes. Implementation of AMM TBIO-1a would reduce this impact but the impact would remain a major adverse effect. However, implementation of one of the Project alternatives identified above could potentially reduce the long-term impacts of coastal processes on the protection of septic systems, leach fields, and homes to be negligible.

Impact CP/GEO-3: Protection of Public Trust Resources, Septic Systems, and Homes from Coastal Processes and Shoreline Erosion

Beach nourishment and dune creation would provide short- to mid-term beneficial effect (10 to 20+ years) through protection of public trust resources and private property from coastal erosion (Beneficial Effect, Class B).

Impact Discussion (CP/GEO-3)

Over the last 20 to 30 years, coastal erosion has eliminated dry sandy beach and damaged coastal dune habitats and environmentally sensitive living resources along Broad Beach, limiting the public's potential for use and enjoyment of these resources. This erosion has also threatened septic systems and the potential release of septic effluent and debris from patios, geotextile revetments, pipes, and homes damaged by wave action and erosion. Oscillation of the width of this beach and shoreline have occurred historically and this coastal erosion appears to be related primarily to natural wave action and longshore transport, not anthropogenic causes, such as climate changed induced SLR or interruption of longshore sand transport by man-made jetties or harbors.[6] However, past and potential future damage to private property and public trust resources remains a major adverse effect.

The Project would initially create a wide sandy beach backed by a system of restored sand dunes placed over and landward of the existing emergency revetment. Although wave action would immediately begin to reshape and erode this beach, these features would substantially reduce the potential for coastal erosion and the landward migration of the shoreline over the short- to mid-term. Although the effect of wave action and natural coastal processes on this beach are difficult to forecast precisely, with one major

[6] Interruption of longshore transport from the Santa Barbara Littoral Cell to the Santa Monica Littoral Cell by landward erosion of the Point Mugu Submarine Canyon may have substantially decreased down coast transport of sand to Broad Beach and other area beaches, contributing to beach erosion.

renourishment and annual backpassing, the benefits of creation of a wide sandy beach and dune system on public access, creation of sensitive habitat, and protection of homes and septic systems are estimated to endure over 10 to 20 years depending on a variety of factors as discussed below.

The GENESIS model created by Moffatt & Nichol provides the most conservative estimates for the longevity and duration of the proposed new beach and dune system. This model indicates that wave action and longshore transport of newly placed sand would immediately begin to transport sand down coast, possibly exposing the dune system to erosion and requiring major renourishment within 5 years of the initial Project, even with annual backpassing. Based on this worst case modeling, Project benefits of beach and dune creation associated with two nourishment events and backpassing may last as little as 10 years, leading to exposure of the emergency revetment. However, Moffatt & Nichol and Coastal Environments suggest that this worst case analysis contradicts historic trends and does not account for cyclic changes in wave climate related to the PDO index (Orme et al. 2011).

Using historic erosion rates over the last 2 decades, where Broad Beach has been losing an estimated 35,000 to 45,000 cy/yr down coast to Zuma Beach, and assuming a 25 percent loss of initial nourishment and renourishment material the longshore transport and offshore areas, the total Project life prior to dune erosion and the beginning for potential exposure of the revetment could be 16 to 20 years, which could potential be extended by a further 6 to 8 years with backpassing. Under this scenario, the Project would provide benefits for the intended 20-year life of the Project as the emergency revetment would remain buried under the dune system, and the beach fronting the revetment would protect public trust resources and private property from coastal erosion and related impacts. This scenario appears to be the most likely given that it is supported by both Moffatt & Nichol and Coastal Environments and is supported by long-term empirical observations of how this beach is performing.

Backpassing could substantially extend beach life by roughly 6 to 8 years over the life of the Project if a conservative long-term average of 25,000 cy/yr is backpassed, for total of approximately 500,000 cy over the Project life. However, backpassing success could be affected by two factors. First, as with initial nourishment, a substantial portion of backpassed sand (estimated at as much as 25 percent) would be lost from the post-construction beach. Further, as beach widths decrease, it is unclear how much sand would be available for each event. In early post-nourishment years, the full Applicant-proposed 25,000 to 35,000 cy may be available, which would likely decline toward the end of the useful life of each nourishment event. Further, wave action, climate, and SLR toward the end of the period may affect success. While this makes estimating added years of beach life associated with backpassing difficult, based on an overall sand mass of 500,000 cy backpassed and observed erosion rates of up to 45,000 cy/yr, an estimate of roughly 6 to 8 years appears reasonable.

Although the above scenarios attempt to predict the longevity of beach nourishment, precise estimates are not possible. As is typical of other locations along California's shoreline, Broad Beach has historically undergone long-term oscillations in beach width. Evidence exists that this shoreline location has varied from as far landward as the currently inactive sea cliff 300 feet landward of the current beach, to the much wider sandy beach of the 1970s. Without intervention, current trends in erosion could lead to elimination of the historic back beach, dune complex, homes, and other improvements constructed upon these relatively recent coastal features. However, the potential also exists for changing climactic weather patterns and associated changes in the direction and intensity of incoming swells, sand supply, and associated longshore transport to shift to the pattern that occurred in the 1960s and 1970s, with accretion of sediment aiding in longer retention of the beach and dunes created by the Project.

In summary, the Project would create beneficial effects associated with limiting coastal erosion and landward migration of the shoreline and considerably minimize any possible impacts of destruction of septic systems, homes and other improvements on public trust resources and the public use and enjoyment of such resources. These benefits would endure for the duration of the nourishment, currently estimated to last approximately 10 to 20 years or more, with backpassing extending beach life further. Renourishment after this period is unknown, with potential shoreline retreat if nourishment does not continue or keep pace with erosion. Without future renourishment events, the emergency revetment would potentially become exposed resulting in substantial coastal erosion impacts over the longer term. In addition, sand bag revetments would offer interim protection during storm events and would generally not be impacted by geologic processes, but would be subject to destruction from wave attack. Their inclusion in the project would provide periods of short-term protection for the dunes, homes and OWTS during major events. However, the impacts from limiting coastal erosion and landward migration of the shoreline over the life of the Project are considered to be a beneficial effect over the timeframe that they endure.

Impact CP/GEO-4: Sand Size and Angularity Compatibility of Inland Sand Sources with Existing Sand on Broad Beach

Quarry sand being used as beach fill on Broad Beach is similar to existing sand on Broad Beach in size composition, color, and particle angularity. (Negligible Effect, Class N).

<u>Impact Discussion (CP/GEO-4)</u>

Studies conducted in August (URS) and November (Moffatt & Nichol) of 2013 assessed the angularity and size of sand particles from Broad Beach and the Local Inland Sand Sources. Particle angularity is a measure of particle roundness and sphericity. The angularity of beach particles relates to the mobility of the particles with more angular particles having less mobility. Less angular particles are rounder and smoother and are more likely to be eroded by coastal processes.

The grain size of beach sediments are an important factor in beach stability and the retention of sand on a particular beach. In general, coarse-grained sand is less easily mobilized by wave action and transported off or down coast of a beach than fined-grained sand or sediment. Projects using larger particles for beach fill in the San Diego Area have been monitored to observe how the supplemental sand changes overtime (BBGHAD 2013). Based on observations from previous projects using coarser than native sand as beach fill, it is expected that a beach consisting of grains sizes seen at the Local Inland Sources would be wide, with a steeper upper beach profile slope that what would be seen east of Broad Beach, along Zuma Beach. This condition will be more pronounced immediately after construction and for approximately the first post-nourishment year as the new sand temporarily dominates the surface condition. The beach will then gradually revert toward a pre-construction condition as the new sand disperses and mixes with finer sand reaching the beach from updrift via littoral processes, and the beach profile equilibrates. As the sand disperses and mixes over time, the condition of the beach will continue to trend toward pre-project conditions and ultimately will revert to that state within approximately a decade prior to any renourishment. Backpassing may not significantly change this trend due to the relatively small quantity of material to be moved compared to the total volume of sand placed as nourishment (BBGHAD 2013).

The assessments determined that overall angularity of the sand is not appreciably different between the Local Inland Sand Source Sites and the receiving beach and dunes; therefore, the impact related to sand angularity would be negligible.

Local Inland Sources are slightly larger than native particles on the beach. This would result in a slightly steeper beach and a longer residence time for fill material on Broad Beach. Impacts from coarser-than-native beach fill would be negligible.

Impact CP/GEO-5: Impacts of Beach Nourishment and Dune Creation on Coastal Processes

Nourishment of the beach would have insignificant effects on wave height, wave direction, tides and currents (Negligible Effect, Class N).

Impact Discussion (CP/GEO-5)

Placing sand on Broad Beach would not change the general wave climate in the area. Waves are generated a distance away from Broad Beach in deep water and propagate to the coast. Waves break when the wave height exceeds 0.78 times the water depth, and then they propagate as a bore. After the fill is completed and the beach has reached its equilibrium, the beach slope would be gentler than it is at present. As a result, waves would break farther seaward from the existing shoreline; currently they are breaking at the toe of the revetment. The wave breaker height would be less than the height of waves currently approaching the revetment due to the gentler slope of the placed sand. There would be no noticeable changes in the wave characteristics (i.e., height, period, direction) offshore of the surf zone.

Impacts to surf conditions at Broad Beach would likely be positive. Most beach breaks in Southern California are made of sandbars, which become altered and sometimes improved when nourishments increase sand volumes. The dynamics of sandbars, which include increased sand volumes of similar grain size and wider beach widths, contribute to a more tidally dependent surf zone. This creates multiple variations in the nearshore bathymetry and improves the sandbars and wave shape quality for surfers. Broad Beach fill will likely improve surfing conditions at Broad Beach and Zuma Beach because of the increased size of the sand bars at both beaches due to the import of 600,000 cy of beach sand. Surf breaks at or west of Lechuza Point will not be affected since the predominant longshore transport is to the east (see also Impact REC-4).

Broad Beach has a mixed semidiurnal (daily) tide with two high tides and two low tides, of different magnitude, every 24 hours and 50 minutes. The range between mean high and low water is approximately 3.7 feet and the diurnal range is approximately 5.4 feet. Tidal characteristics in the Broad Beach vicinity range from a lowest observed tide of 2.7 feet below MLLW to a highest observed tide of 7.8 feet above MLLW.

Coastal currents have two components: alongshore and cross-shore. These currents are present outside the surf zone (offshore of wave breaking points) and controlled by large weather systems, winds, and tides; therefore, the Project would not have impacts on the magnitude or directions of these currents. Longshore currents are generated by energy dissipation in the breaking waves inside the surf zone. These currents flow parallel to the shore. The flow is caused by an oblique angle of the wave (angle between wave approach and shoreline normal) and an alongshore variation in wave height. Longshore currents are responsible for transporting sand along the coast. Their magnitude is sensitive to any changes in the angle between wave approach and shoreline direction. Longshore currents are also randomly variable and there are changes in their magnitude and direction seasonally, annually, and inter-annually. The proposed fill would result in changes to the magnitude and direction of the longshore currents; however, these changes will be within the natural variability of their values.

Impact CP/GEO-6: Impacts of Beach Nourishment and Dune Creation on Wave Run-Up

Nourishment of the beach would have beneficial effects on wave run-up (Beneficial Effect, Class B).

Impact Discussion (CP/GEO-6)

Wave run-up is defined as the rush of water up a beach or coastal structure that is caused by or associated with wave-breaking. The run-up elevation is the maximum vertical height above 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, beach slope and porosity, and if a structure is present, that structure's shape, slope roughness, permeability, and water depth at the toe.

Moffatt & Nichol (2013) estimated predicted run-up and overtopping for extreme wave and water level events under existing conditions at Broad Beach, incorporating predicted SLR for the year 2040. Predicted run-up ranges from 15 to 16 feet above the design still water level, resulting in run-up elevations of 23 to 25 feet above MLLW. These potential run-up elevations are higher than the crest height of the existing revetment, which is 12 to 15 feet MLLW, meaning waves would overtop the revetment during extreme wave and water level events. These run-up elevations represent the current condition in which there is little to no beach fronting the revetment.

After the beach fill, wave run-up values would be less than those values presented by Moffatt & Nichol for the same wave conditions because: 1) waves would break farther away from the shoreline; and 2) as the broken wave propagates along the beach slope, waves would lose a considerable part of their energy. Reduced wave run-up would reduce potential impacts to public trust resources, as well as private septic systems and residences. Therefore, reduced wave run-up as a result of the Project would produce a beneficial impact for as long as the effects of nourishment persist (10 to 20 years). Upon erosion of the beach and cessation of nourishment, wave run up would again reach and potentially overtop the revetment as discussed in Impact CP/GEO-7 below.

Prior to installation of the emergency revetment there was a variety of different individual coastal protection structures, including rock, timber, geotextile, and Sakrete revetments. Given that these structures were smaller than the emergency revetment and the wave environment is the same, these structures were subject to even greater and more frequent overtopping than the emergency revetment. Therefore, implementation of the Project would provide even greater benefit to protection of public trust resources and private septic systems and residences when compared to the pre-revetment condition, than when compared to the existing condition.

Impact CP/GEO-7: Change in Sediment Transport to Down Coast Beaches

Nourishment of Broad Beach will increase down shore sediment transport to Zuma Beach, Westward Beach, Point Dume, and other down coast beaches in the Public Trust Impact Area (Beneficial Effect, Class B).

Impact Discussion (CP/GEO-7)

Sand placed at Broad Beach would be distributed along the coast by longshore currents. Net transport down coast toward Zuma Beach, Westward Beach, and Point Dume State Beach is estimated at 35,000 to 45,000 cy/yr. Effects of the longshore currents on nourishment and renourishment of sand in the short- to mid-term include both erosion of sand from Broad Beach and accretion of sand at down coast beaches and possibly offshore.

The average sand volume changes at Broad Beach between 1946 through 2007 were about 21,000 cy/yr; the estimated volume change in the beach after beach fill is completed would be from 35,000 to 45,000 cy/yr. Therefore, the increase in the rate of sand gain from west to east would range from approximately 14,000 cy/yr to 19,000 cy/yr, which would have positive impacts on Zuma Beach, Westward Beach, and Point Dume State Beach, as well as other down coast beaches, as longshore transport carries the sand west through the Zuma Littoral Subcell, past Point Dume, and eastward through the Santa Monica Littoral Cell. Therefore, this impact is beneficial to public trust resources. Please see Section 3.3, *Marine Biological Resources*, Impact MB-2 for a discussion of potential impacts to down coast rocky intertidal habitats.

A variety of different individual coastal protection structures, including rock, timber, geotextile, and Sakrete revetments existed before the emergency revetment was installed. These structures were less robust than the emergency revetment and were subject to potential failure during large wave events and additional erosion. If the emergency revetment were to fail, the subsequent erosion would move sand from Broad Beach into the littoral cell and down coast. With Project implementation, 500,000 cy of sand would be used to construct the new beach berm. This sand would be subject to littoral processes and would contribute sand to the littoral zone without resulting in erosion landward of the existing emergency revetment where there are currently septic systems and residences that could be damaged. Therefore, the Project would allow for continued sediment transport to down coast beaches without subjecting public trust resources and private property to substantial erosion and associated damage.

The related Trancas Creek restoration and Caltrans bridge construction projects may also mobilize sediment into the littoral zone and contribute sediment to down coast beaches. Deposition of 600,000 cy of sand onto Broad Beach and its gradual erosion and contribution to littoral drift would potentially alter the frequency and duration of breaching of the Trancas Creek Lagoon though widening of the beach berm. (See

Impacts T-BIO-5, MB-7 and MWQ-1.) These impacts would be limited to the duration of the construction activities and to the first storms following construction that may carry this sediment to the ocean. These impacts would be short-term and incremental.

Impact CP/GEO-8: Impacts of Sea Level Rise

Sea level rise would incrementally contribute to erosion of the proposed new beach over the 10- to 20-year Project life span (Negligible Effect, Class N).

Impact Discussion (CP/GEO-8)

SLR will incrementally contribute to the erosion rate for the Project's widened beach over the Project's 20-year life through 2034. Sea-level rise over the short- to mid-term Project horizon (e.g., 10 to 20 years) is projected to accelerate to approximately 5.8 inches by 2030 and 8.5 inches by 2040. Moffatt & Nichol (2013) estimate that under these projections, SLR over the next 20 years would contribute to approximately 3 to 15 feet of beach erosion along most of Broad Beach where the slope is expected to be 10 horizontal feet to each vertical foot (10:1) and approximately 1 to 4.5 feet of erosion at the west end of Broad Beach where the slope is expected to be 3:1. Since the Project would increase beach widths by 90 to 230 feet seaward of the new dune system after initial nourishment and renourishment, the 1 to 15 feet of erosion attributable to SLR over the Project life would comprise a small portion of the erosion along Broad Beach. Therefore, this impact is negligible over the 20-year Project life. However, higher sea levels which are projected to accelerate after 2050 may substantially accelerate coastal erosion, potentially exposing the restored dunes, emergency revetment, homes, and septic systems with possible direct and secondary effects on public trust resources.

3.1.8 Summary of Coastal Processes, Sea Level Rise, and Geologic Hazards Impacts and AMMs

Impact	Class	AMM
CP/GEO-1: Structural Stability of the Rock and proposed Sand Bag Revetments	**Mj**	**AMM TBIO-1a.** Implementation of a Comprehensive Dune Restoration Plan.
CP/GEO-2: Impact of Coastal Processes on Emergency and Sand Bag Revetments	**Mj**	**AMM TBIO-1a.** Implementation of a Comprehensive Dune Restoration Plan.
CP/GEO-3: Protection of Public Trust Resources, Septic Systems, and Homes from Coastal Processes and Shoreline Erosion	**N**	No AMMs recommended
CP/GEO-4: Sand Size and Angularity Compatibility of Inland Sand Sources with Existing Sand on Broad Beach	**N**	No AMMs recommended
CP/GEO-5: Impacts of Beach Nourishment and Dune Creation on Coastal Processes	**N**	No AMMs recommended
CP/GEO-6: Impacts of Beach Nourishment and Dune Creation on Wave Run-Up	**B**	No AMMs recommended
CP/GEO-7: Change in Sediment Transport to Down Coast Beaches	**B**	No AMMs recommended
CP/GEO-8: Impacts of Sea Level Rise	**N**	No AMMs recommended