Encinitas-Solana Beach Coastal Storm Damage Reduction Project

San Diego County, California

Appendix C

Geotechnical Engineering

U.S. Army Corps of Engineers
Los Angeles District

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1 INTRODUCTION

This Appendix documents the variations in shoreline erosion susceptibility along the 39,500-foot-long section of shoreline comprising the coastal Cities of Encinitas and Solana Beach in northern San Diego County. Storms in recent decades have removed sand beaches, and major bluff failures have recently occurred along this portion of the coast, giving rise to uncertainty about future bluff stability and rates of bluff retreat.

2 PHYSIOGRAPHY AND GEOLOGY

The coastline of the Cities of Encinitas and Solana Beach extends from the south side of Batiquitos Lagoon a distance of approximately 7.5 miles (mi) south to the projection of Via De La Valle, the southern city limits of Solana Beach. The coastal bluffs extend south an additional 0.3 mi to the San Dieguito River Valley. The San Elijo Lagoon separates the Cities of Encinitas and Solana Beach, with the mouth of this coastal wetland being approximately 5,000 feet (ft) in width. Excluding San Elijo Lagoon, Fletcher Cove (Solana Beach), and Moonlight Beach (Encinitas), this reach of coastline consists of steep coastal bluffs. The bluffs range in height from approximately 40 ft along San Elijo State Beach, to 120 ft at “I” Street, both areas within the City of Encinitas. The bluffs in Solana Beach range from approximately 70 ft at South Cardiff State Beach to 90 ft just south of Fletcher Cove. Both Fletcher Cove and Moonlight Beach represent the westerly terminus of small drainages within each of these cities; Fletcher Cove draining an upland area of approximately 200 acres (ac) and Moonlight Beach draining an upland area of 2,500 ac. Both of these drainages contain storm drains discharging onto their respective coastal beaches.

The study area is bounded by the Batiquitos and San Dieguito Lagoons; both significant drainages extending from 15 to 40 mi into the back county, with the San Dieguito River Valley extending to the crest of the Laguna Mountains. The somewhat smaller San Elijo Lagoon separating these two coastal communities drains Escondido Creek, with its upland watershed extending about 25 mi to the east. The road fill for the Pacific Coast Highway, where it crosses San Elijo Lagoon, is at an elevation of approximately 15 ft.

Prior to the establishment of extensive cultural development along the bluff top within the City of Encinitas, natural local drainage was over the bluff onto the beach. An ancient beach ridge forms the crest of the coastal terrace, which creates a drainage divide 50 to 500 ft back from the bluffs, thus limiting over-bluff discharges to localized runoff. This runoff was well distributed along the coast, with limited concentration by the topography at any one point.

Coastal development in Encinitas modified the natural drainage pattern. The bluff-top streets (Neptune Avenue, 4th Street, Sea Lane Drive, and Pacific Coast Highway) generally capture inland runoff and direct it to the lagoons or to the canyon at Moonlight Beach. Residences along the bluff are built at elevations slightly above, to below, street elevation. Consequently, drainage is over the bluff from many lots and significant parts of all lots. Areas with poor drainage exist along Neptune Avenue at Phoebe and Avocado Streets, where runoff is directed into storm drains passing through private property, over the bluff, to the beach.

The natural pre-development topography along Solana Beach also exhibited an ancient beach ridge atop the coastal terrace; with the drainage divide typically 50 ft back from the contemporary bluff top, thus limiting over-bluff discharges to localized runoff. South of 525 Pacific Avenue, the terrace surface slopes away from the bluffs, preventing any over-bluff discharge. Development has not modified the natural drainage pattern, except within individual residential lots. With the exception of a few of the north lots, the residences along the bluff in Solana Beach are built at elevations above street elevation. Consequently, drainage from the bluff-top lots in Solana Beach is almost entirely to the street. Backyards of a few of the north lots are below the adjacent street level and, at these locations, a small amount of surface drainage discharges over the bluff to the beach. Similarly, backyards of a few of the south lots appear to have indefinite drainage, suggesting that locally, a small amount of backyard runoff south of 525 Pacific Avenue may also discharge over the bluff.

Unlike Encinitas, the topography of the coastal bluff top along Solana Beach precludes virtually all over-bluff discharge and, thus, natural subaerial erosion processes in Solana Beach are less active than the Encinitas coastline and, for that matter, the majority of San Diego County's upper sloping coastal bluffs. Subaerial erosion is a process of coastal cliff erosion that is primarily from terrestrial derived forces verses marine erosion, which is from ocean derived forces. Marine erosion generally is caused by wave induced erosion from the ocean. The causes of subaerial erosion are commonly a mixture of: storm or sheet runoff from direct precipitation that results in rilling and scarring and direct erosion/washing away of the cliff faces; wind that causes abrasion and removal/transport of loose soil and rock particles from the cliff faces; and groundwater seepage exiting from the cliff faces that mobilizes and removes soil and rock from the cliff faces and results in voids and cavities along the cliff face.

2.1 Geology.

2.1.1 Regional Geology

The San Diego coastal area consists of a dissected coastal plain underlain by Cretaceous, Tertiary, and Quaternary sedimentary strata that rest unconformably on an igneous and metamorphic basement of late Jurassic and Cretaceous age.

The crystalline basement rocks underlying the San Diego coastal area are metamorphosed volcanic rocks of the Jurassic age Santiago Peak Volcanics that are intruded by granitic rocks of the Southern California Batholith. These rocks crop out in the mountainous eastern portion of the province. A thick section of fluviatile, marginal marine and marine sediments of late Cretaceous through recent age rests unconformably on the crystalline basement. A thick sequence of interbedded sandstone, siltstone, and claystones of the La Jolla Group was deposited during the Eocene Epoch and is exposed at the base of the coastal bluffs. Unconformably overlying the Eocene formations are Pleistocene marine terrace deposits of sand and silt. At least nine marine terraces, trending nearly parallel to the present day shoreline, are preserved along the stretch of coast from Carlsbad to Solana Beach.

The geologic structure of this part of the Southern California coastline has formed in response to faulting and folding associated with the opening of the Gulf of California along the San Andreas fault zone and associated faults. Localized gentle folding and minor faulting of the Eocene sediments is evident. The Rose Canyon fault zone, located about 2-3 mi west of the study area, is part of a regional, northwest-trending fault zone that includes the Offshore Zone of Deformation and the Newport-Inglewood fault to the north, and several possible extensions southward, both onshore and offshore.

The geologic units present in the Encinitas/Solana Beach area include Holocene non-marine dune sands and late Pleistocene marine terrace deposits that form the sloping, upper coastal bluffs above the sea cliffs, and older Eocene "bedrock" geologic units that form the lower cliffed portion of the bluffs (Eisenberg, 1985; Tan, 1986, 1996).

2.1.2 Eocene-Age Sea Cliff-Forming Units

Three Eocene epoch aged (approximately 38 to 53 million years ago before present) geologic (bedrock) units are exposed from north to south along the Encinitas coastline, with the southernmost two Eocene units exposed along the Solana Beach coastline. The exposed units are: the Santiago Formation (a.k.a. Scripps Formation), the Torrey Sandstone, and the Delmar Formation. The approximate areal extent of these relatively resistant, cliff-forming bedrock geologic units is shown on **Figure 2.1-1**. These bedrock units are all members of the larger La Jolla Group geologic formation unit. The La Jolla Group consists of six distinct members, all of Eocene age. They are listed in order from youngest age to oldest geologic age, as follows: Friars Formation, Scripps Formation (Santiago Formation), Ardath Shale, Torrey Sandstone, Delmar Formation and Mount Soledad Formation. All are present as exposed and mapped bedrock outcrops along the entire San Diego County coast. As previously mentioned, only three of these six bedrock members (the Santiago and Delmar Formations and Torrey Sandstone) are exposed within the project study area. The Ardath Shale, Friars and Mount Soledad Formations are not exposed within the project study area. The three bedrock units in general are composed of a sedimentary rock that ranges in grain size from coarse to fine. The coarse portions are composed mostly of sandstone and conglomerate, while the fine portions are made up of, shale, claystone and siltstone. The claystone and siltstone portions are further lumped together and described as a clayey facies or clayey part of the bedrock formation. This clayey or clayey faces descriptive terminology is analogous to what is commonly used in the engineering discipline to describe soils that are either clay or silt or mixtures of both, i.e. the fines portion of the engineering classification of soils methodology (Unified Soils Classification System (USCS). The lithology and relationship of these three geologic bedrock units to the overall geology of the coastal bluffs in San Diego County is shown on the stratigraphic column section (**Figure 2.1-2**).

<u>Santiago Formation (a.k.a. Scripps Formation):</u> This bedrock formation includes both a sandy and clayey facies extending from south Oceanside down to the 700 block of Neptune Avenue. It is a part of the La Jolla Group bedrock formation. The sandy facies exposed north of 1680 Neptune Avenue is well-indurated, light yellow-brown, massive sandstone (Wilson, 1972; Eisenberg, 1985; Tan, 1996). The clayey facies of the Santiago Formation, previously classified as Ardath Shale (Eisenberg, 1985; Tan, 1986; Group Delta, 1993), is exposed south of 1680 Neptune Avenue and consists of landslide-prone siltstones and claystones (Tan, 1996). The clayey facies of the Santiago Formation is predominantly weakly fissile, olive-gray (predominantly kaolinitic) clayey shale with interbedded sands, commonly containing concretions and fossil assemblages. As discussed in greater detail in Section 2.3, landslide susceptibility in this geologic unit appears to be controlled, in part, by faulting, with the most landslide susceptible section extending from Beacons south to the 700 block of Neptune Avenue.

<u>Torrey Sandstone:</u> This bedrock is a well-indurated, white-gray to light yellow-brown, medium- to coarse-grained sandstone. The lower portions of the Torrey Sandstone contain bioturbated beds and concretions, while the upper portions exhibit high-angle cross-bedding (Kennedy and Peterson, 1975).

<u>Delmar Formation:</u> This bedrock formation is a moderately well-indurated, yellow-green and olive-gray, sandy claystone, interbedded with medium gray, coarse-grained sandstone. This geologic unit also comprises the more erosion-resistant offshore reefs, including Swamis Reef off the Self Realization Fellowship, Cardiff Reef off Restaurant Row, and Table Tops Reef along the north edge of the Solana Beach coastal bluffs. Abundant well-cemented oyster beds locally

exist within this geologic unit, substantially contributing to its erosion resistance and are also responsible for the presence of the three above-referenced reefs. All of the reefs extend some distance offshore (Kennedy and Peterson, 1975). The Table Tops Reef is locally faulted and several small length faults have been mapped at the surface of this reef. The faults can be seen exposed on the nearshore portions of the reef. The existence of these faults has contributed to the differential coastal bluff erosion near the reefs. For the most part, the reef has continually being eroded as part of the overall nearshore platform, but has is slightly higher in this area because of localized uplift. The faulting is the evidence and expression of this localized uplift and therefore the erosion of the reef and the nearby bluff is considered fault controlled.

2.1.3 Pleistocene-Age Bluff-Forming Units

The sloping upper portion of the coastal bluffs is comprised of late-Pleistocene marine terrace deposits, including sediments from a variety of geologic environments. The marine terraces are a landform consisting of bench-like relatively flat areas adjacent to the coastal bluffs. In the Encinitas and Solana Beach areas, the sediments consist of moderately-consolidated, poorly-indurated, light reddish-brown, silty fine sands and clean sands that include both nearshore marine sediments, and beach and dune sands. The marine terrace deposits overlie a wave-cut abrasion platform, formed on the Eocene bedrock approximately 120,000 years ago when sea level was 20 ft higher (Lajoie and others, 1992). At that time, the sea was at a high eustatic level due to substantial melting of the ice caps during an interglacial period. Today, the abrasion platform ranges in elevation from approximately 17 ft near Batiquitos Lagoon, to approximately 70 ft at San Elijo State Beach, with the majority of the abrasion platform elevation along the Solana Beach coastline at or near 25 ft (MSL datum). The difference in elevation is a result of variable regional uplift associated with gentle tectonic folding during the past 120,000 years. Based on their location underlying the major marine terrace adjacent to the coast and overlying the abrasion platform, the sediments in the coastal bluff of the Encinitas/Solana Beach coast are correlated with the Bay Point Formation (approximately 120,000 years old).

The terrace deposits throughout virtually the entire study area are capped by an approximately 10-foot-thick, iron-oxide-cemented, residual clayey sand deposit. This upper Bay Point, erosion-resistant capping material, formed by the concentration of clayey weathering products, secondary oxides of iron and aluminum, and leached and re-precipitated salts, is the result of long exposure to the elements during a period of tropical to temperate climate.

Throughout much of Solana Beach, horizontally-bedded clean sand beach deposits exist within the lower part of this geologic unit. Wherever these clean sands are exposed by a cliff failure, the bluff becomes unstable and susceptible to failure. Ongoing and progressive upper-bluff failures continue to this day along the north portion of the Solana Beach coastline. Overlying the beach sands are thick sand dune deposits, which comprise much of the middle Bay Point Formation in this area and likely part of a dune field that overran the beach deposits after the sea retreated. These clean relic beach sands and thick overlying dune deposits do not appear to exist along the Encinitas shoreline, and, for that matter, have not been encountered in other Bay Point Formation exposures extending from the Point Loma Peninsula in central San Diego, up to the north limits of San Diego County. Along the Encinitas coast, the middle Bay Point Formation is divided into sections by ledge-forming units created by short term operation of the same processes that formed the resistant cap of the upper Bay Point. Each ledge forming unit represents a period when sedimentation was interrupted long enough for the weathering process to add some induration to the sediments. As a result, the tall sections of loose dune sand, which are so problematic for bluff stability in Solana Beach, are absent in most of Encinitas.

Pleistocene-Age Canyon Alluvial Fill: Fletcher Cove is bounded on the north and south by the walls of an ancient stream valley filled by Quaternary-age alluvium, talus and marine estuary sediments. This infilled stream valley pre-dates the deposition of the overlying Bay Point Formation (approximately 120,000 years old). As a cliff-forming geologic unit, this material is more erodible than the adjacent Torrey Sandstone and, hence, has allowed approximately 80 ft of differential erosion beyond that of the more linear coastal bluff forming what is today Fletcher Cove.

It should also be noted that the depression in the coastal bluff in this area, i.e., within the upper terrace surface, represents an excavation made in the late 1920s to provide a visual and recreational amenity in this North County community, and is not of geologic or geomorphic origin. Prior to the excavation, however, this area did originally drain to the coastal bluff, with its small upland watershed extending easterly to Pacific Coast Highway.

2.1.4 Geologic Structure

The geologic structure of the Encinitas/Solana Beach coastline is the result of faulting and folding in the current tectonic regime, which began approximately 5,000,000 years ago when the Gulf of California began to open in association with renewed movement on the San Andreas fault system (Fisher and Mills, 1991). The nearest member of the fault system is the Rose Canyon fault zone running approximately parallel to the coast, two to three mi offshore. Movement along the fault appears to have caused gentle folding on the coastal side of the fault. The gentle folding has, in turn, caused a small southeast dip in the Eocene-age formations, thus exposing progressively older formations north along the coast. In more recent times, the 120,000-year-old wave-cut abrasion platform has been tilted to the northwest at about 0.1 degree.

Tectonic forces are also evident in the localized folding and faulting of the Eocene-age sediments. The episodes of faulting and long-continued tectonic stresses have resulted in hundreds of visible joints, fractures and shear zones having micro- to large-scale variations in erosion potential. Downdropping associated with some of these faults has resulted in the juxtaposition of the Eocene-age geologic units in Encinitas, most notably the sandy and clayey facies of the Santiago Formation near the Grandview Stairs and the contact between the Santiago and Torrey Sandstone near 730 Neptune Avenue. Faulting has also juxtaposed the Delmar Formation against the Torrey Sandstone below 633 Pacific Avenue, with the Delmar Formation upthrust against the Torrey Sandstone and likely contributing to the presence of Table Tops Reef just to the north.

Most of the sea caves along the Encinitas/Solana Beach coastline formed along these Pleistocene-age faults where fractures and shear zones allow differential erosion and the propagation of a sea cave along the axis of the fault (Kennedy, 1973). Fault-induced sea caves are most notable north of Tide Park in northern Solana Beach and most prevalent within the Torrey Sandstone, with most of these sea caves since filled in and at least partially responsible for most of the existing seawalls in Solana Beach and in the 500 to 700 block of Neptune Avenue in Encinitas.

2.1.5 Onshore Geology

A thick sequence of resistant, cliff-forming, interbedded sandstone, siltstone, and claystone is exposed in the Encinitas and Solana Beach coastal bluffs. These bluffs, which range in height from 30 to 100 ft, are formed by the La Jolla Group of Eocene age, and include the Del Mar Sand, Torrey Sand, and the Santiago Formation. Within the Encinitas segment of the coastline, the sequence of formational material from north to south consists of the Santiago, Torrey Sandstone and Delmar formations. Along the Solana Beach shore, the geological units exposed are the Delmar formation along the northern segment and the Torrey Sandstone in the southern portion.

Within the study area, the Del Mar Formation generally consists of yellowish green sandy claystone overlain by a mudstone layer. Overlying the Del Mar formation is the Torrey Sandstone, a well-indurated, white to light tan, medium to coarse-grained sandstone that is generally cross-bedded. The Santiago Formation, which overlies the Torrey Sandstone, includes well-indurated light yellow-brown sandstone, as well as a clayey olive gray clay shale facies.

The sloping upper portion of the coastal bluffs are formed by late Pleistocene marine terrace deposits (correlated with the Bay Point Formation) which are composed of moderately consolidated, poorly indurated, light reddish brown, silty fine sands.

Offshore from the bluffs, a shore platform extends 500 to 900 ft seaward at a slope of 1.25 degrees to a depth of 12 ft, followed by a steeper slope of 1.75 degrees to depths of over 60 ft. In general, the offshore bathymetric contours within the Encinitas and Solana Beach coastal region are gently curving and fairly uniform. In addition, the nearshore contours are relatively straight and parallel. See **Appendix B** for a discussion of the bathymetry offshore of the study area.

2.1.6 Offshore Geology

The offshore area adjacent to Encinitas and Solana Beach is composed of a relatively thin veneer of unconsolidated marine sediments covering a wave-cut bedrock platform composed of interbedded sandstone, siltstones, and claystones of the Eocene Torrey Sandstone/Del Mar/Santiago Formations. Where the less erosion-resistant Torrey Sandstone underlies the platform, deeper water extends closer to the bluffs. The more erosion-resistant offshore reefs, including Swami's Reef, Cardiff Reef, and Table Tops Reef are formed by Del Mar sandstone. Abundant well-cemented oyster beds within the Del Mar Sand unit at the reefs contribute to its erosion resistance.

During the past 10,000 years, worldwide sea level has risen in response to glacial retreat. Before then, the sea level was about 350 ft lower than at present. At that time, the courses of major San Diego County Rivers had cut down their channels and extended much further offshore. As sea level raised the rivers backfilled their channels and rose with the sea level. Most of the potential borrow areas in this study are located within these former paleochannels (drowned river channels). These paleochannels represent the thickest local accumulation of nearshore sediment.

These paleochannels are typically incised or cut into Quaternary or Tertiary sedimentary bedrock formations. These same bedrock formations are exposed along the coastal bluffs of the study area and form the onshore portion of the geology of the study area.

The basal portions of the paleochannels may contain fluvial deposits. As seen within onshore water well logs, these materials are relatively coarse grained. However, based on available offshore data, it seems unlikely that fluvial deposits are within potential dredge depths to be captured as borrow material. Significant portions of the paleochannel within potential dredge depths include estuary, lagoon and littoral deposits. The estuary/lagoonal deposits would represent relatively low energy depositional environments, and are areas where fine grained sediments would have been deposited. Intertidal beach deposits are chiefly well sorted (poorly graded) sand, often with some gravel and shells. The sediment sequence offshore is typically capped at the seafloor with fine grained sediments, which are from pelagic (open ocean) sedimentation and nearshore sediment influx during flood periods. These surface layers of sediment make up the silt cover often found in varying thickness in the nearshore. The littoral deposits, sometimes described as “relict beaches”, are therefore the ideal targeted offshore environment for potential borrow area materials.

San Elijo Lagoon is underlain by up to 150 ft of Pleistocene-Quaternary alluvial and marine deposits filling a buried valley cut into the Tertiary bedrock. These sediments consist of a combination of unconsolidated sands, silts, and clays with rare layers of gravel and cobbles. The deeper sediments were deposited in an open bay, and are primarily composed of medium to fine sands. Studies by Leighton and Associates (1991) identified the buried Escondido Creek channel which is filled with lagoonal sediment, extends offshore at least 3,280 ft, and is more than 98 ft deep. This channel lies along the sewage outfall alignment, and is probably associated with the channel deepening at the time of the Wisconsin glacial maximum 20,000 years ago.

The major portion of the shoreline within the study area consists of narrow to nonexistent sand and cobble beaches backed by seacliffs. An exception to this is the portion of the shoreline at Cardiff which is a low lying sand spit that fronts San Elijo Lagoon. Ninyo & Moore (1998) note that gravel-cobble berms are common between Encinitas and Del Mar, and “consist of hard, resistant, flattened, smooth-faced gravel and cobbles mostly of igneous and metamorphic composition”.

The depleted beaches along the Encinitas and Solana Beach shoreline have been widened as a result of recent sand replenishment activities. Sands dredged from Batiquitos Lagoon were placed at Batiquitos Beach in 1998 and 2000 to establish a feeder beach that can provide sand to the downcoast shoreline. SANDAG’s Regional Beach Sand Project conducted in 2001 also placed approximately 600,000 cy at Batiquitos Beach, Leucadia, Moonlight Beach, Cardiff and Fletcher Cove (Noble Consultants, 2001). Recent beach profile surveys indicate that the placed sediment has been dispersed alongshore both upcoast and downcoast of the beach-fill sites.

2.1.7 Faulting and Seismicity

The study area is located in a moderately-active seismic region of Southern California that is subject to significant hazards from moderate to large earthquakes. Ground shaking resulting from an earthquake can impact the Encinitas and Solana Beach study area. The estimated peak site acceleration for the maximum probable earthquake is approximately 0.45 of the gravitational acceleration from a magnitude 6.9 earthquake on the offshore Rose Canyon fault zone, occurring at a distance of 2.5 mi to the west of the study area.

No major faults or folds have been mapped within or immediately adjacent to the study area, and the La Jolla formation is essentially flat-lying, with a slight westward dip locally. The faults displayed on the geologic map (**Figure 2.1-1**), i.e. the Beacons and Seawall Faults, are considered to be inactive ancient faults. Some faults locally control the contact between formations. A local gentle southeast dip in the Eocene formations has been produced by weak folding associated with movement along the Rose Canyon fault to the west.

Table 2.1-1 tabulates the seismic parameters for the active faults located within the study area.

Table 2.1-1 Earthquake Fault Summary

Abbreviated Fault Name	Approx. Distance (mi)	Estimated Max. Earthquake Event	
		Maximum Earthquake MAG. (Mw)	Peak Site Ground Acceleration (fraction of gravity)
Rose Canyon	2.5	6.9	0.451
Newport-Inglewood (Offshore)	13.3	6.9	0.167
Coronado Bank	16.6	7.4	0.185
Elsinore-Julian	29.7	7.1	0.086
Elsinore-Temecula	29.8	6.8	0.070
Earthquake Valley	42.4	6.5	0.039
Palos Verdes	42.4	7.1	0.059
Elsinore-Glen Ivy	43.9	6.8	0.046
San Jacinto-Anza	52.4	7.2	0.051
Elsinore-Coyote Mountain	53.5	6.8	0.038
San Jacinto-Coyote Creek	54.6	6.8	0.037
San Jacinto-San Jacinto Valley	54.7	6.9	0.039
Newport-Inglewood (L.A. Basin)	55.5	6.9	0.039
Chino-Central Ave. (Elsinore)	58.3	6.7	0.045
Whittier	61.8	6.8	0.032

Figure 2.1-1 Geologic Sketch Map of the Study Area

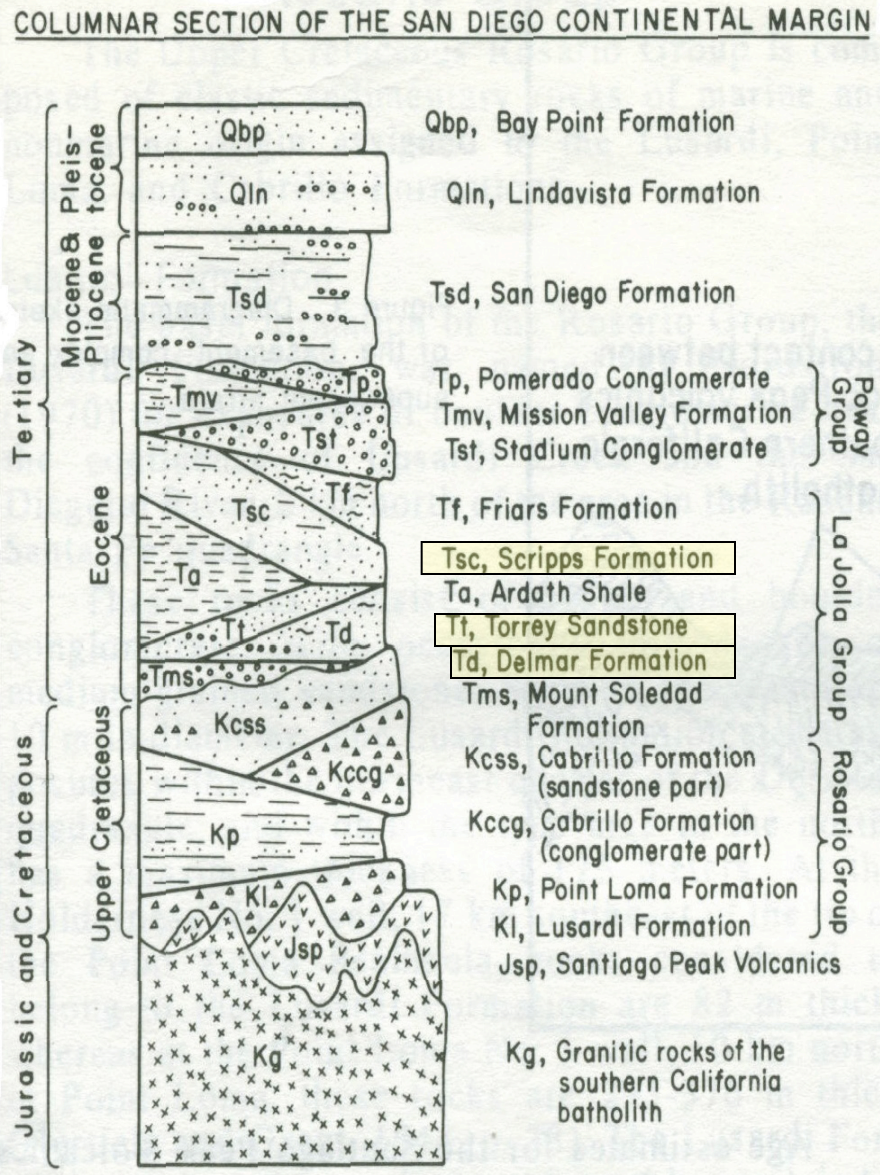

Figure 2.1-2 Geologic stratigraphic column of the study area, with three geologic units of study area, highlighted in yellow 🟨

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2.2 Groundwater

An important contributor to the erosion of coastal bluffs in the Encinitas area, and particularly within the Delmar Formation, is the flow of groundwater along the contact between the pervious, moderately-consolidated, coastal terrace deposits and the well-consolidated, less pervious, Eocene formations that underlie the terrace deposits, and along faults and fractures in the Eocene bedrock. The likely sources of this groundwater are: 1) natural groundwater migration from highland areas to the east of the terrace, and 2) infiltration of the terrace surface by rainfall, and by agricultural and residential irrigation water (Turner, 1981). The volume of groundwater exiting the bluff face in the site area varies from location-to-location, and between seasons, even during drought years.

Although limited amounts of groundwater likely also exit the coastal bluffs in Solana Beach, the topographic relief, with upwards of 20 ft of fall from the coastal bluff to Pacific Coast Highway, and then ample gradient to San Elijo Lagoon to the north and Fletcher Cove to the south, limits the volume of initial infiltration as a groundwater source affecting the coastal bluffs in Solana Beach. Additionally, unlike the less pervious Eocene formations farther north, the underlying Torrey Sandstone does not create an impermeable perching horizon, which would encourage groundwater to exit the bluff face along the contact between the coastal terrace deposits and the underlying cliff-forming Eocene-age formation. One exception does exist in Solana Beach, with groundwater accumulating on the abrasion surface of the Pleistocene fluvial deposits underlying Fletcher Cove where phreatophytes exist, suggesting an almost continuous localized flow of groundwater in this area.

2.3 Landsliding

A landslide occurred on June 2, 1996, damaging six homes in the 800 block of Neptune Avenue, and significantly increasing the level of concern regarding landsliding in the Eocene cliff-forming sediments. There was also a landslide adjacent to Beacons about 125 ft to the north, on which an unimproved public access to the beach currently exists. The Beacons landslide has episodically moved small amounts during the past half century, primarily during those times when the beach sands have been scoured off the bedrock shore platform, removing overburden at the base of the landslide. A third landslide exists in the 700 block of Neptune Avenue, where movement has again occurred along a weak clay seam near the base of the sea cliff along this section of coastline. The three landslides all failed along a weak remolded clay seam dipping slightly seaward near the base of the Eocene-age Santiago claystone.

As indicated in Elliott's paper, and in other papers and geotechnical reports (Hart, 2000; TerraCosta, 2002a, b, c), the high susceptibility to landslides in parts of the Eocene sediments along the Encinitas and Solana Beach coastlines appears to, in part, be fault-controlled and generally confined between the Beacons fault and the Seawall fault over an approximately 0.3-mile section of coastline, including and extending south of Beacons. It should be noted, however, that the entire clayey facies of the Santiago Formation and the clay-rich Delmar Formation are both considered to be slide-prone geologic units, with the potential for landslides controlled by both remolded clay seams within these Eocene sediments and the presence of groundwater. The groundwater provides both hydrostatic driving forces and dilatency within the bluff-parallel joints near the bluff face, leading to an increase in water content and culminating in a drop in shear strength to a fully softened value.

2.4 Coastal Bluff Geomorphology

2.4.1 Terminology for the Bluff and Adjacent Shore

The geomorphology of a typical coastal-bluff profile is a shore platform, a lower near-vertical cliffed surface called the sea cliff, and an upper bluff slope generally ranging in inclination between 35 and 65 degrees (measured from the horizontal). The bluff top is the boundary between the upper bluff and the flat to gently sloping coastal terrace.

Offshore from the sea cliff is an area of indefinite extent called the nearshore zone. The bedrock surface in the nearshore zone, which extends out to sea from the base of the sea cliff, is the shore platform. Worldwide, the shore platform may vary in inclination from horizontal, to a gradient of three horizontal to one vertical, or 33- percent (Trenhaile, 1987). Offshore from the Encinitas/Solana Beach coastline, the gradient of the shore platform ranges from approximately one to two percent. The boundary between the sea cliff (the lower, vertical and near-vertical section of the bluff) and the shore platform is called the cliff-platform junction, or shoreline angle.

Within the nearshore zone is a subdivision called the inshore zone, beginning where the waves begin to break. This boundary varies with time because the point at which waves begin to break is a function of wave height, tidal level, and sand level. During low tides, large waves will begin to break far out to sea. During high tide, waves may not break at all, or they may break directly on the lower sea cliff. Closer to shore is the foreshore zone, that portion of the shore lying between the upper limit of wave wash at high tide and the ordinary low water mark. Both of these boundaries usually lie on a sand or shingle beach. More importantly, at least in northern Solana Beach, insufficient sand beach exists today to support the backshore, or elevated beach, which typically remains dry and defines the landward edge of the foreshore. Thus, depending on the extent of the transient sand or shingle beach, the foreshore often extends to the sea cliff and allows waves, on a daily basis, to impact directly upon, and actively erode, the coastal bluff.

2.4.2 Classification of Bluff Geometry

Assessing the rate of coastal retreat requires an understanding of the dynamic relationship between the upper bluff and sea cliff. Emery and Kuhn (1982) developed a global system of classification of coastal bluff profiles, and applied that system to the San Diego County coastline from San Onofre State Park to the south tip of Point Loma. In their regional study, the Encinitas/Solana Beach area is designated as Type “C (c)”. The letter “C” designates coastal bluffs having a resistant geologic formation at the bottom, and less resistant materials in the upper parts of the bluff. The relative effectiveness of marine erosion of the lower resistant formation, compared to subaerial erosion of the upper bluff, produces a characteristic profile. Rapid marine erosion compared to subaerial erosion produces a steep overall bluff, whereas slower marine erosion produces a more gently-sloping upper bluff. The letter “(c)” indicates that the long-term rate of subaerial erosion is approximately equal to that of marine erosion. Where the upper-bluff terrace deposits are undergoing active subaerial erosion, the slope face is slightly concave. Where subaerial erosion is less active, it is slightly convex.

Local geologic variations within the study area create a derivative of the Type “C(c)” bluff. The geologic sections along the Encinitas/Solana Beach coast show a partially-cemented cap of beach ridge sediments. In these areas, where the cap erodes more slowly and protects the underlying uncemented sediments, the upper bluff will retreat more in accordance with the Type “B(c)” bluffs in the Emery and Kuhn classification, maintaining a steeper profile.

3 MECHANICS OF CLIFF EROSION

The Encinitas/Solana Beach coastline has experienced a measurable amount of erosion in the last 20 to 30 years, with the most significant amount of erosion occurring during periods of heavy storm surf in the absence of a protective sand beach. The entire base of the sea cliff throughout the study area has been exposed to direct wave attack in the last 20 years, with the fairly persistent shingle beach in northern Encinitas (north of Beacons) and the SANDAG beach fill project at least partially protecting portions of the coastal bluffs. The waves erode the sea cliff by mechanical abrasion at the base of the sea cliff, and by impact on small joints and fissures in the otherwise massive rock units, and by water-hammer effects (marine erosion). The upper bluffs, which typically support little or no vegetation, are subject to wave spray and splash, sometimes causing saturation of the outer layer and subsequent sloughing of oversteepened slopes. Wind, rain, irrigation and uncontrolled surface runoff contribute to minor erosion of the upper coastal bluff, especially on the more exposed, oversteepened portions of the friable sands (subaerial erosion). Where these processes are active, rilling has resulted along portions of the upper bluffs.

Bluff-top retreat under natural conditions is the end result of erosion processes (both marine and subaerial) acting primarily on the sea cliff and upper bluff. The contribution from erosion of the coastal terrace (landward of the bluff top) is generally smaller and can be reduced to negligible amounts by careful landscaping, control of surface runoff, and prevention of human traffic near the bluff top.

Geomorphic techniques can be used to describe the progressive nature of bluff-top retreat. This requires breaking the problem down into upper and lower bluff (sea cliff) component processes, and developing an understanding of the interaction between the two components.

Although bluff retreat is episodic and site-specific, characteristically coinciding with major storm events, the rates of retreat of both upper and lower components of the bluffs are approximately equal over the longer term (defined here as several hundreds of years). Continuing long-term retreat of the lower bluff gradually creates an oversteepened slope in the upper bluff, causing it to decline (by erosion and/or slope failure) to a more sustainable slope angle. The process continues and repeats in a series of episodes.

Pre-anthropogenic erosion rates have accelerated in part due to increased storminess, but primarily due to the loss of sand, with notable increases in coastal erosion affecting the Encinitas shoreline following the 1982-83 El Niño storm season, and the Solana Beach shoreline following the 1997-98 El Niño storm season. During investigations, it was noted that the upper bluff slope inclinations in Encinitas ranged between approximately 35 and 65 degrees, while at the same time the Solana Beach upper bluff slope inclinations ranged between approximately 37 and 53 degrees. As the upper-bluff slope approaches the high end of this range, episodes of massive slope failure are typically caused by insufficient soil strengths to sustain the steeper slope angles, and are often aggravated by the combined effects of groundwater seepage and rainfall.

Important to this discussion, however, is that throughout the study area, upper-bluff failures were relatively infrequent prior to the 1982-83 El Niño storms in Encinitas and the 1997-98 El Niño storm season in Solana Beach. With the more pervasive loss of beach sand, the sea cliff throughout the study area has been more persistently subjected to direct wave attack, with surf zone abrasion notching the base of the sea cliffs and the overhang eventually collapsing when the weight of the overhang exceeds the strength of the Eocene cliff rock supporting it. The failure of the sea cliff then undermines the sloping upper terrace deposits and, particularly where clean sands exist; accelerated sloughing of the clean sands in turn undermines the upper terrace deposits. This triggers the progressive failures extending up the face of the coastal bluff.

The typical mechanism of subaerial erosion and upper-bluff retreat is one of progressive sloughing, resulting in upper-bluff slope decline. This impact of marine erosion on subaerial erosion, and the process by which marine erosion of the sea cliff continually acts to steepen the relatively gently-sloping upper bluff surface from the bottom-up of a Type “C(c)” coastal bluff, which does not have a cemented cap.

Considerable investigative work has been conducted on the process and mechanisms of slope decline in an attempt to date fault scarps, which are subsequently affected by subaerial erosion. Wallace (1977) developed slope decline criteria for weakly indurated Pleistocene deposits similar to that of the North County San Diego marine terrace sands. The initial steeper section of the curve represents more rapid decline from about 10 to 100 years of age, primarily associated with progressive surficial slumping. Below an inclination of about 35 degrees, coincident with a 100-year age date, decline continues at a much slower rate, primarily associated with rilling, rain impact, raveling, and in-place weathering.

As part of a coastal bluff study conducted in Encinitas, Dr. Shlemon, a noted Quaternary Geologist, was able to determine pedogenesis, suggesting in-place weathering void of any coastal bluff erosion for a period of approximately 75 to 100 years within the northernmost section of Encinitas (north of Beacons). In this area, relatively stable upper-bluff slopes of 35 to 40 degrees, consistent with those described by Wallace (1977), suggested essentially no subaerial erosion dating back to the 1890s, and thus suggesting no substantive marine erosion during this same time period (Group Delta, 1993). Upper-bluff slopes within the remainder of the study area are typically steeper and do not appear to have a developing pedon, and particularly within the south portions of Encinitas, these steeper slopes indicate much younger ages.

Coastal bluffs that have a resistant cap of partially-cemented sand or other soil are more resistant to slope decline and behave more like the type “B(c)” bluff in the Emery and Kuhn (1982) classification. The cap appears to protect the underlying upper bluff from attack by rain and runoff, which weakens the intergranular structure of unprotected sediment. The rate of erosion of the partially cemented cap is much slower than the rate of unprotected sediment and influences the rate of bluff retreat. The cap is subject to undermining by progressive slumping and erosion working its way upward from the sea cliff. The Wallace curve likely underestimates the contribution of the erosion resistant cap, and where this exists, coastal bluffs can sustain higher slope angles than predicted by the Wallace curve [the slopes in northern Encinitas where Dr. Shlemon found developing pedogenic horizons, did not have the cemented cap typical of most of southern Encinitas and the Solana Beach coastline].

Upper-bluff failures progress considerably faster, and are typically more severe, with the typical Solana Beach profile, i.e., a relic basal clean sand layer and overlying sand dunes. The principal difference revolves around the ease with which the clean sands become dislodged and removed, thereby undermining the upper sloping terrace deposits in a progressive failure, with episodic and occasionally spectacular collapses of the upper bluff terrace deposits as a result of insufficient shear strength.

3.1 Groundwater Contributions

Groundwater seepage exiting the bluff face on top of the Eocene bedrock units tends to cause spring sapping and solution cavities along faults, joints and bedding planes, helping to locally accelerate marine erosion and contribute to subaerial erosion in these areas. Additionally, as groundwater approaches the bluff face, it infiltrates near-surface, stress-relief, bluff-parallel joints, which form naturally behind and parallel to the bluff face. Hydrostatic loading of bluff-parallel (and sub-parallel) joints contributes to block-toppling failures in the lower cliffed sections of the bluff.

Excluding those areas where the sea cliff is comprised of the Torrey Sandstone, groundwater seepage exists locally throughout most of Encinitas at the contact between the middle Eocene bedrock and the overlying Quaternary-age terrace deposits. The area of Encinitas underlain by the Delmar Formation (south of Moonlight) is highly susceptible to groundwater-induced bluff failures. Geotechnical studies have indicated that groundwater within the Delmar Formation has weakened bedding planes and joints, resulting in a higher susceptibility to blockfall failure, with as many as 30 blockfalls or block-glide failures occurring between 1971 and 1978 (Kuhn and Shepard, 1980). Although recent attempts to control groundwater have significantly reduced the potential for blockfall failure within the Delmar Formation, in the area of the Self Realization Fellowship Church, blockfall failures continue to be a problem further to the north, with numerous failures still occurring between F and I Streets.

Problems associated with groundwater seepage in Solana Beach are limited to the clayey Pleistocene-age canyon infill in Fletcher Cove, where groundwater seepage has likely contributed to numerous minor failures in that area.

4 ANALYTICAL METHODS

In its broadest sense, geomorphology deals with land forms and their evolution over time. Lithology, or the description of the physical character of rocks, can also be used to estimate the relative erosion resistance of the intact, non-fractured rock. Geologic structure, which includes structural discontinuities such as jointing and faults, can be used to estimate variations in erosion resistance within a particular lithologic unit. Coastal processes include waves impacting upon coastal bluffs. This is the basic source of erosive energy, which is modified by the nearshore and offshore bathymetry, and by sea level elevation relative to the nearshore bathymetry. More recently, natural coastal geomorphic processes have been influenced by anthropogenic activities.

The methodologies most useful in assessing relative rates of coastal erosion are divided into five general separate categories:

1. Historical analyses;
2. Geomorphic analyses;
3. Anthropogenic influences;
4. Impact of long-term sea level change; and
5. Empirical and analytical techniques.

Coastal geologists and geomorphologists traditionally employ the first three techniques, often relying on interpretation of maps and aerial photographs. However, such historical data usually cover a short time span and may be limited to small-scale maps and photographs such that significant errors may occur in estimating the amount and rate of shoreline change. If the available maps and photographs cover only a quiescent climatic period, underestimates are likely.

An entirely independent method of assessing the rate of coastal erosion is to consider long-term (geologic) sea level change, which is a major factor determining coastal evolution (Emery and Aubrey, 1991). Sea level rise drives coastal erosion, and when using relatively coarse time scales, that is, thousands of years, the rate of cliff erosion over a given time is equal to the rate of sea level rise divided by the shore platform slope. This sea level model takes the following form (Marine Board, 1987):

$$dx/dt = (L + E) / \text{platform gradient}$$

where, dx/dt is the horizontal rate of erosion, L is the local tectonic rate of subsidence or uplift, and E is the eustatic sea level rise. Although the sea level model is excellent when considering geologic time scales, say on the order of thousands of years, it has relatively low applicability when estimating erosion rates for a project design life of 50 years.

These first four methodologies are discussed in considerable detail in the 1996 Reconnaissance Report and, for brevity, have not been repeated. The fifth methodology, the empirical and analytical techniques have been more fully developed as part of this feasibility study. The geotechnical elements associated with the empirical cliff erosion model originally proposed by Sunamura (1977) are discussed in the following paragraphs.

4.1 Empirical and Analytical Techniques

The scientific community has been actively engaged in developing numerical models to assess rates of shoreline erosion. Numerical models attempt to address both the landward retreat of the sea cliff, and the development of the shore platform. In its simplest expression, predictive cliff-erosion models take the following form (Sunamura, 1977):

$$dx/dt \; \% \; \ln(fw/fr)$$

where dx/dt is the horizontal rate of erosion, f_w is the wave force, and f_r is the rock resistance. Similar equations have been developed to describe platform downwearing, z, with the rate of downwearing often expressed as a function of sea cliff erosion rate times platform gradient (Zenkovitch 1967):

$$dz/dt = dz/dt \text{ X } \tan m$$

where $\tan m$ is the platform gradient.

The elevation of the cliff-platform junction is also a function of rock strength, and within a given geomorphic environment, higher rock strengths correspond to higher cliff-platform junction elevations (Trenhaile, 1987). Throughout San Diego's North County, where the Eocene-age cliff-forming material exhibits similar rock strengths, the cliff-platform junction is typically around –1 foot, MSL, with the Santiago and Delmar Formations being slightly higher, possibly around elevation 0 to +1 foot. Where the Eocene oyster beds are occasionally encountered in the Delmar Formation claystones, the calcium carbonate-rich deposits, with their high unconfined compressive strengths, provide extremely erosion-resistant nearshore reefs, with the cliff-platform junction elevation locally as high as 7 ft, MSL [Table Tops Reef] and nearshore elevation differentials as high as 10 ft [measured along the south margin of Swamis Reef at 20-

foot water depth]. These Eocene-age oyster beds are also responsible for some of North County's best surf breaks, notably Swamis, Cardiff, and Table Tops.

The rock resistance, f_r, is determined principally by the mechanical strength, which is related to its lithology and geologic structure, such as jointing, faulting and rock stratigraphy. The unconfined compressive strength of rock is a common geotechnical parameter, and used in Sunamura's work (1977, 1981), by Benumof and Griggs (1999), and for this study. Assuming that f_w and f_r can be expressed as follows:

$$f_w = A\rho g H$$
$$f_r = BS_c$$

where H is the wave height at the cliff base, S_c is the compressive strength of the material forming the cliff base, ρ is the density of water, g is the gravitational acceleration, and A and B are nondimensional constants, the general equation reduces to:

$$\frac{dx}{dt} = k\left(C + \ln\frac{\rho g H}{S_c}\right)$$

where C is a nondimensional constant (= ln (A/B)) and k is a constant with units of [LT^{-1}]. The unknown constants C and k can then be determined empirically from recession data for different intervals, assuming that the wave conditions and cliff strength are known (Sunamura, 1981). For a measured wave environment and measured amount of erosion for a given time interval, an empirical bluff erosion model can then be developed.

The unconfined compressive strength of intact bedrock should be corrected to account for the many structural imperfections that exist along a coastal bluff, including such items as the weathered profile, joint spacing, joint orientation, width of joints, and continuity of joints. The presence of groundwater is also an important parameter. Rock mass classifications have been developed within the geotechnical community for characterization of rock stability, with a geomechanics classification proposed by Bieniawski (1979) and Selby (1980). Sunamura used the Selby classification with the aid of the Schmidt Hammer in his development of unconfined compressive strengths of Tertiary-age rocks in Japan (Sunamura, 1992), and this approach was also used by Benumof and Griggs (1999) in their evaluation of sea cliff erosion rates on cliff material properties and physical processes in San Diego County. The geomechanics classification of jointed rock masses developed by Bieniawski has been reproduced in **Table 4.1-1**, and the relationship developed by Benumof and Griggs (1999), incorporating the Schmidt Hammer to estimate unconfined compressive strengths, is presented in **Table 4.1-2**.

Table 4.1-1 Geomechanics Classification of Jointed Rock Masses. After Bieniawski (1979)

A. Classification Parameters and their Ratings

	Parameter		Ranges of Values				
1	Strength of intact rock material	Point-load strength index	>10 MPa	4—10 MPa	2—4 MPa	1—2 MPa	For this low range — uniaxial compressive test is preferred
		Uniaxial compressive strength	>250 MPa	100—250 MPa	50—100 MPa	25—50 MPa	5—25 MPa 1—5 MPa <1 MPa
	Rating		15	12	7	4	2 1 0
2	Drill core quality *RQD*		90 %—100 %	75 %—90 %	50 %—75 %	25 %—50 %	<25 %
	Rating		20	17	13	8	3
3	Spacing of discontinuities		>2 m	0.6—2 m	200—600 mm	60—200 mm	<60 mm
	Rating		20	15	10	8	5
4	Condition of discontinuities		Very rough surface Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation <1 mm Slightly weathered walls	Slightly rough surfaces Separation <1 mm Highly weathered walls	Slickensided surfaces OR Gouge <5 mm thick OR Separation 1—5 mm Continuous	Soft gouge >5 mm thick OR Separation >5 mm Continuous
	Rating		30	25	20	10	0
5	Ground water	Inflow per 10 m tunnel length	None	<10 litres / min	10—25 litres / min	25—125 litres / min	>125 litres/min
		Ratio $\frac{\text{joint water pressure}}{\text{major principal stress}}$	OR 0	OR 0,0—0,1	OR 0,1—0,2	OR 0,2—0,5	OR >0,5
		General conditions	OR Completely dry	OR Damp	OR Wet	OR Dripping	OR Flowing
	Rating		15	10	7	4	0

B. Rating Adjustment for Joint Orientations

Strike and dip orientations of joints		Very favourable	Favourable	Fair	Unfavourable	Very unfavourable
Ratings	Tunnels	0	—2	—5	—10	—12
	Foundations	0	—2	—7	—15	—25
	Slopes	0	—5	—25	—50	—60

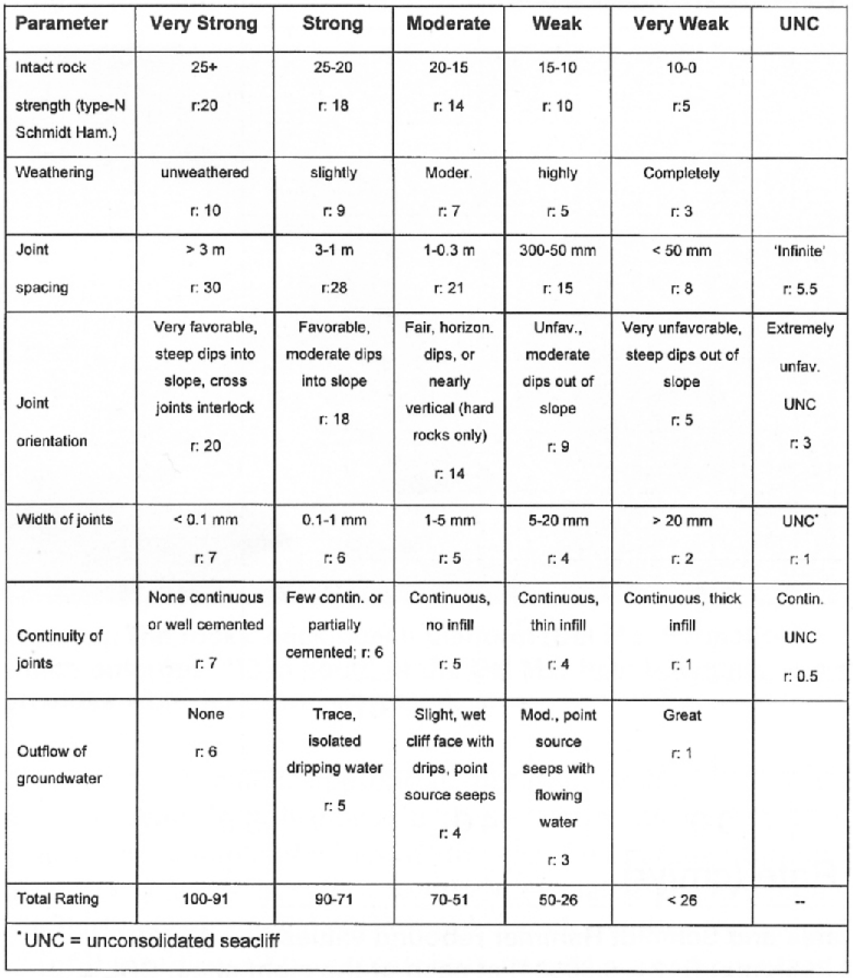
C. Rock Mass Classes Determined from Total Ratings

Rating	100←81	80←61	60←41	40←21	<20
Class No.	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

D. Meaning of Rock Mass Classes

Class No.	I	II	III	IV	V
Average stand-up time	10 years for 15 m span	6 months for 8 m span	1 week for 5 m span	10 hours for 2,5 m span	30 minutes for 1 m span
Cohesion of the rock mass	>400 kPa	300—400 kPa	200—300 kPa	100—200 kPa	<100 kPa
Friction angle of the rock mass	>45 °	35 °—45 °	25 °—35 °	15 °—25 °	<15 °

Table 4.1-2 Geomorphic Rock Mass Strength Classification and Ratings



Parameter	Very Strong	Strong	Moderate	Weak	Very Weak	UNC
Intact rock strength (type-N Schmidt Ham.)	25+ r:20	25-20 r: 18	20-15 r: 14	15-10 r: 10	10-0 r:5	
Weathering	unweathered r: 10	slightly r: 9	Moder. r: 7	highly r: 5	Completely r: 3	
Joint spacing	> 3 m r: 30	3-1 m r:28	1-0.3 m r: 21	300-50 mm r: 15	< 50 mm r: 8	'Infinite' r: 5.5
Joint orientation	Very favorable, steep dips into slope, cross joints interlock r: 20	Favorable, moderate dips into slope r: 18	Fair, horizon. dips, or nearly vertical (hard rocks only) r: 14	Unfav., moderate dips out of slope r: 9	Very unfavorable, steep dips out of slope r: 5	Extremely unfav. UNC r: 3
Width of joints	< 0.1 mm r: 7	0.1-1 mm r: 6	1-5 mm r: 5	5-20 mm r: 4	> 20 mm r: 2	UNC* r: 1
Continuity of joints	None continuous or well cemented r: 7	Few contin. or partially cemented: r: 6	Continuous, no infill r: 5	Continuous, thin infill r: 4	Continuous, thick infill r: 1	Contin. UNC r: 0.5
Outflow of groundwater	None r: 6	Trace, isolated dripping water r: 5	Slight, wet cliff face with drips, point source seeps r: 4	Mod., point source seeps with flowing water r: 3	Great r: 1	
Total Rating	100-91	90-71	70-51	50-26	< 26	--

*UNC = unconsolidated seacliff

Geomorphic indicators are also useful for empirically evaluating shoreline erosion rates, with the following factors considered:

- Bluff profile and height;
- Concavity versus convexity of terrace deposits;
- Eocene bedrock/Quaternary terrace contact elevations;
- Elevation and slope of the shore platform;
- Relative erosion resistance of lithologic units;
- Presence of sea caves;
- Frequency and pattern of fractures, joints and faults;
- Groundwater seepage;
- Presence of shingle and/or sand beach at base of bluffs;
- Presence of a weathering profile; and
- Presence of protective vegetation.

As should be apparent from the list of geomorphic indicators, all of the classification criteria contained in the Bieniawski and Selby geomechanics classifications are included, along with the topographic indicators suggested by Emery and Kuhn, the height and composition of the bluff profile and its associated volume available for temporary talus slope protection (Trenhaile, 1987), and one of the most important features being the presence of a shingle and/or sand beach at the base of the bluff. Recognizing that this transient feature cannot be relied upon to protect the bluff, its presence, however, if persistent, will protect the bluff, in essence reducing Sunamura's f_w, significantly reducing or stopping ongoing marine erosion.

5 COASTAL RETREAT IN THE ENCINITAS/SOLANA BEACH REGION

Before anthropogenic changes in the 20th Century, the coastal bluffs retreated in accordance with long-term sea level rise since the last glacial maximum. By approximately 6,000 years ago, sea level had rapidly risen to within 12 to 16 ft of the present level. The rate then slowed by an order of magnitude to approximately 0.002 foot per year from an earlier rate of 0.028 foot per year. The configuration of the bluffs was similar to the pre-anthropogenic configuration throughout the more recent period of slow sea level rise, consisting of a transient sandy beach, sea cliffs and upper bluffs. Using this history of sea level rise, the geologic retreat rate before anthropogenic changes can be estimated by finding the distance on the shore platform between the sea level or the sea cliff and the 12- and 16-foot depth contours. Where the base of sea cliff is below sea level, an assumption is made that the same condition existed previously and the depth below sea level is used to adjust the 12-foot or 16-foot depth downward. Anthropogenic influences typically consist of flood protection and intensive urbanized and or modern agricultural development that has occurred within the last ±125 years along the coastal areas in the vicinity of the project. This type of influence has gradually reduced the available load of sediment that was naturally present in larger amounts as beach nourishment fill during pre-anthropogenic times.

For the Encinitas/Solana Beach coast, eleven profiles of nearshore bathymetry are available in Appendix B. Evaluation of these profiles using the 12-foot depth indicates the geologic rate of coastal bluff retreat is 0.11 foot per year, with about 640 ft of retreat occurring gradually in the last 6,000 years (**Table 4.1-1**). The same method applied to a profile at La Jolla indicates a similar rate. Using the 16-foot depth, bluff retreat in the same period was 0.14 foot per year.

Table 4.1-1 Geologic (Pre-Anthropengic) Rate of Coastal-Bluff Retreat

Transect	Location	Reach No.	Source	R_{total}* (ft)	R/yr (ft/yr)	0 to -12' Shore Platform Slope
SD710	Parliament Road	1	COE	509	0.085	0.024
SD700	Grandview Street	1	COE	639	0.107	0.019
SD695	Jupiter Street	1	COE	658	0.110	0.018
SD690	Jason Street	1	COE	654	0.109	0.018
SD680	Beacons Beach	2	COE	695	0.116	0.017
SD675	Stone Steps	3 / 4	COE	651	0.109	0.018
SD670	Moonlight Beach	4 / 5	COE	640	0.107	0.019
SD660	Swami's	6	COE	580	0.097	0.021
SD650	San Elijo Park	6	COE	635	0.106	0.019
SD620	Seaside	7 / 8	COE	670	0.112	0.018
SD600	Fletcher Cove	8	COE	696	0.116	0.017
Average: Using 12-foot depth Using 16-foot depth				639 852	0.107 0.142	0.019

* Total retreat measured from sea level to 12-foot depth contour, based on the profile that shows the least sand.

A retreat rate of 0.11 to 0.14 foot per year would suggest an equilibrium beach width of about 90 to 100 ft, based on the relationship developed by Everts (1991). This may represent the long-term average pre-anthropogenic beach width during the last 6,000 years. The significant and fairly pervasive loss of the protective sand beach over the last 20 to 30 years has significantly increased the pre-anthropogenic average coastal bluff retreat rate, primarily affecting the area south of Beacons in Encinitas and the majority of the Solana Beach coastline.

The 1996 Reconnaissance Report goes into some detail discussing estimates of retreat rates based on a sea level rise model and the available historical data extending up through 1995. Of most importance was the recognition that, in the community of Encinitas, and particularly south of Beacons, there was a significant increase in shoreline erosion during and continuously after the 1982-83 El Niño storm season, with sea cliff erosion rates approaching 1 foot per year in Reach 2 (Jensen, 1995) [Reach 3 in this study]. Other erosion studies in the vicinity of Grandview (Reach 1) from the period 1975 through 1988, which again included the 1982-83 El Niño storm season, developed average sea cliff erosion rates of 0.47 foot per year, and annualized bluff-top erosion rates of 0.4 foot per year (Woodward-Clyde, 1988); the lower bluff-top rates resulting from some initial lag in the bluff-top erosion rate due to the relatively gentle upper bluff slope steepening in response to marine erosion in the early period of the project design life.

During this same time period, the Solana Beach shoreline, although experiencing limited marine erosion, had virtually no sea cliff failures of sufficient size to undermine the upper terrace deposits, and, with minor exceptions, essentially no recognizable upper-bluff subaerial erosion (Group Delta, 1998).

A severe El Niño storm season occurred during the winter season of 1997-98, and the cities of both Encinitas and Solana Beach have experienced significant shoreline erosion affecting both the sea cliff and the bluff top, with locally over 15 ft of bluff-top retreat significantly impacting existing bluff-top improvements. A variety of improvements exist and consist mostly of structural engineering remedies in the form of: seawalls, rip-rap rock revetments, concrete/shotcreting of bluff slope surfaces and sea cliff/sea cave notch filling. During this period of time, both coastal communities have experienced an almost total loss of protective sand beach [the significant cobble berm north of Beacons has been partially eroded, displacing some of the gravel to the south], with significant coastal erosion photographically recorded during this six-year period.

The relatively extensive Oakley photo collection has provided invaluable contemporary erosion data throughout Encinitas in the absence of a protective sand beach, and the Solana Beach City Lifeguards, along with Group Delta Consultants, TerraCosta Consulting Group, and several private homeowners, have also provided excellent photographic documentation of the significant erosion in Solana Beach. Again, virtually all of this erosion has occurred in the absence of any protective sand beach, and the SANDAG Regional Beach Sand Project (RBSP) I, which placed 441,000 cy of sand in Encinitas and 146,000 cy of sand in Solana Beach during the Spring of 2001, has to a limited extent, changed the sand-starved character of this North County coastline.

5.1 The Effect of Variable Beach Width on Sea Cliff Retreat

The seasonal transient sand beach along the Encinitas coast appears to have been relatively stable until about 1940 when anthropogenic influences had accumulated to the point that the beach began a gradual decline. By 1983, storms and an intensified wave environment had entirely removed the sand beach, exposing the underlying shore platform and, where present, the underlying shingle berms. This sand has not since returned.

The effect of beach loss on the retreat rate of sea cliff faces was evaluated by Everts (1991). It was concluded that the retreat rate could increase in order of magnitude, depending on the original beach width and the erosion resistance of the Eocene-age bedrock unit exposed in the sea cliff.

For the Encinitas coast, Everts prepared a site-specific graph as part of coastal engineering services for the City of Encinitas (Zeiser-Kling Consultants, 1994), which suggests sea cliff retreat would be approximately 0.4 foot per year with no protective sand beach. This graph also indicated that with a mean beach width of 200 ft, the annualized minimum erosion rate would approach 0.0 foot. This width of beach would need to be maintained and renourished in order that the erosion rate is kept to this minimum. A wide shingle beach that is not mobilized during storms could be as effective as sand in protecting the coast from cliff erosion. However, this type of beach was not evaluated in the 1991 analysis by Everts and will not be considered as an alternative to a sandy type of beach fill proposed for this study. However, a narrow shingle beach, which is likely to be mobilized often, would accelerate erosion above the rate expected for the no-beach condition. The shingle at Stone Steps may be optimum size for frequent mobilization, resulting in the observed high rate of sea cliff retreat in this area.

The initiation of extensive coastal erosion in Solana Beach over a decade later than that observed in Encinitas poses an interesting question; one that is addressed by the speed of the long-term erosion wave that is proceeding downcoast within the Oceanside Littoral Cell. Solana Beach, due to its location south of Encinitas, appears to have enjoyed the benefits of the erosion wave that has passed through Encinitas, originally becoming quite evident in the early 1980s. Large-scale accretion and erosion waves on coastal beaches were initially studied by Inman and Bagnold in 1963, and have been cited by many authors up until the present (Wiegel, 2002). Although large-scale erosion waves noted in Southern California in the 1960s and 1970s typically exhibited alongshore speeds of about 1 mile per year, this longshore movement is driven by the incident wave energy, and the more recent reduction in a net south transport rate (Elwany, et al., 1999) appears to have deferred Solana Beach's erosion problems until the 1997-98 El Niño storm season. More importantly, however, the pervasive and persistent loss of sand, first noted in northern Solana Beach, is now slowly working its way to the south, with more severe coastal erosion anticipated in south Solana Beach in the near future. The recent and significant coastal bluff failures at Surfsong, several hundred ft south of Fletcher Cove attest to this reality.

For the Encinitas/Solana Beach coastline, the pervasive loss of its one-time protective sand beach, and in the absence of any future sand replenishment, the no project condition should be assumed to be a shoreline essentially void of any transient sand beach with the shore platform exposed and a future erosion environment similar to that experienced in the last five years prior to the recent SANDAG sand replenishment project. As a practical matter, this represents a "lowest stable nearshore/beach profile," which, unfortunately for the communities of Encinitas and Solana Beach, provides a worst-case wave attack scenario occurring during future winter storm events. Although somewhat smaller than the significant shingle berm that existed in

Reach 1 prior to the 1997-98 El Niño storm season, Reach 1 still has a reasonably stable shingle berm that will, at least for the near-term, continue to provide protection for this reach.

5.2 Analysis of Bluff Inventory Results

Fifteen representative bluff profiles for the Encinitas coastline and five representative bluff profiles for the Solana Beach coastline were used for the analyses. The relevant topographic, geologic, and nearshore characteristics at the fifteen Encinitas and five Solana Beach profiles are summarized in **Table 5.2-1** and **Table 5.2-2**. Most of these characteristics either influence or result from marine and terrestrial processes, and although there has been no attempt to quantify the relative importance of a given geomorphic characteristic, taken together, they provide a good indicator of susceptibility to bluff-top retreat. **Table 5.2-1** and **Table 5.2-2**, clearly shows that variations in shoreline erosion potential exist, which should be taken into account in developing both erosion rates and other decisions affecting public safety.

Table 5.2-1 Coastal Profile Characteristics for Encinitas

Prominent Location, Cross Streets	La Costa Ave	Andrew Ave	Avocado St.	Range St.	Phoebe St.	Europa St.	Athena St.	El Portal N.	El Portal S.	Roseta St.	"O" St.	"F" St.	"H" St.	Swam	San Elijo
North – South Address/ Block	2000 North	1800 North	1564 Neptune	1500 Neptune	1200 Neptune	900 Neptune	700 Neptune	500 Neptune	300 Neptune	150 Neptune	400 South	600 South	800 South	1200 South	1400 South
Geologic Cross Sections	C-1	C-2	C-3	C-4	C-5	C-6	C-7	C-8	C-9	C-10	C-11	C-12	C-13	C-14	C-15
Topography															
Elev of Coastal Terrace	65'	75'	70'	75'	80'	95'	80'	85'	85'	75'	70'	95'	110'	100'	83'
Top Elev (height) of Bluff	60' (48')	75'(62')	60'(48')	75'(64')	75'(69')	92'(86')	78'(75')	80'(75)	80'(75')	72'(65')	60'(48')	94'(88')	102'(98')	98'(77')	82'(71')
Slope of Bluff-Upper /Lower	38°/57°	37.5°/55°	35°/44°	36°/56°	28°/56°	37°	35°	48°	50°	51°	38°	39°	42.5°	35.5°	61°
Shape of Bluff	Convex	Convex	Convex	Convex	Convex	Convex	Convex	Concave	Concave	Undulating	Concave	Undulating	Flat	Concave	Concave
Top Elev (height) of Sea Cliff	15'(3')	18'(5')	20'(6')	20'(9')	18'(12')	20'(14')	21'(18')	29'(24')	29'(24')	30'(23')	31'(19')	34'(28')	35'(31')	39'(48')	69'(58')
Elev. Of Beach at Sea Cliff	12'	13'	14'	11'	6'	6'	3'	5'	5'	1'	12'	6'	4'	21' At Rip Rap	11'
Slope of Sea Cliff	87°	87°	87°	88°	87°	86°	88°	88°	88°	88°	88°	81°	86°	85°	88°
Elev of Shoreline Platform	3'	3'	3'	3'	3'	2'	7'	2'	1'	1'	2'	5'	2'	7'	3'
Vegetation, Drainage, Landscape Plan-type Percent Plant Cover Landscape-Structures	Ice Plant 60%	Ice Plant 60%	I.G. Bushes 95% Seawall	Drought Tol. / Ice Plant	Ice Plant 70% 6' Drain PVT	Ice Plant SM BSHS 50%	Bushes 90% Seawall	Ice Plant 10%	Ice Plant 40%	Ice Plant/ Bushes 70%	Ice plant 50%	Ice Plant/ Native 25% 4' Drain PVT	Ice Plant Uppr/LWR 90%/20%	Bushes/ Ice Plant 90%	Ice Plant/ Native 80%
Geologic Formations/ Structures Eocene- Age Geologic Formation Rock Type Bedding	Santiago Sandstone None Mod-High	Santiago Sandstone None Mod-High	Ardath Clystin/Sndstn Interbedded Mod-High	Ardath Clystin/Sndstn Interbedded Mod-High	Ardath Clystin/Sndstn Interbedded Mod-High	Ardath Clystin/Sndstn Interbedded Mod-High	Torrey Sandstone Horiz Old Landslide	Torrey Sandstone Horiz Low	Torrey Sandstone Horiz Low	Torrey Sandstone Horiz Low	Torrey Sandstone Crss Bedded Low/ V. Low	Delmar Clystn/ Sndstn Intrbdd/ Mass LClly/ V. Low	Delmar Clystn/Sndstn Intrbdd/ Mass Lclly/ V.Low	Delmar Clystn/Sndstn Intrbdd/ Mass Lclly/ V.Low	Delmar Clystn/Sndstn Intrbdd/ Mass Lclly/ V.Low
Relative Erosion Resistance Fractures/ Joints Faults Eocene/ Quaternary Contact Elev	Lwr-Bluff Mstly Covrd 15' Low	Tght Frct/ Jts 18' Low	LWR Bluff Mstly Covrd 20' Low	Tght Jnts 3' Sea Cave Sm Fault 20' Low-Mod	Tght Jnts 5' Sea Cave Sm Fault 18' Low-Mod	Tght Jnts 8' Sea Cave 20' Low-Mod	Jnt Sub-Blff LG Fault 21' Low-Mod	Jnt Sub-Blff 29' Mod-High	Jnt Sub-Blff 29' Mod-High	Jnt Sub-Blff 30' Mod- High	Jnt Sub-Blff 31' Mod-High	Jnt Sub-Blff Wk Clay Beds 34' Moderate	Jnt Sub-Blff Wk Clay Beds 35' Mod-High	Jnt Sub-Blff 39' Low	Jnt Sub-Blff 69' Mod-High

Marine Erosion															
Subaerial Erosion	Low	Low	Low	Low	Low	Low	Low	Low-Mod	Low-Mod	Low-Mod	Mod-High	High	High	High	Moderate
Terrace Deposits Soil Type Induration (Upper/Lower) Bluff Soil Development Subaerial Erosion	Sc/Sm Poor Limited Mod-High	Sc/Sm Poor Limited Mod-High	Sc/Sm Poor Limited Moderate	Sc/Sm Poor Moderate Moderate	Sc/Sm Poor Limited Moderate	Sc/Sm Poor None Moderate	Sc/Sm Poor None Moderate	Sc/Sm Poor None Moderate	Sc/Sm Poor None High	Sc/Sm Poor None High	Sc/Sm Poor None Mod-High	Sc/Sm Poor None High	Sc/Sm Poor None High	Sc/Sm Poor None Moderate	Sc/Sm Poor None Mod-Low
Groundwater Elevation Geologic Control – Bedrock Flow Rate	15’ Blockfall Low	18’ Blockfall Low	20’ Cave Fmtn Low	20’ Cave Fmtn Low	18’ Cave Fmtn Low	8’/20’ Blockfall Low	Blockfall	Blw 6’ Blockfall V. Low	Blw 6’ Blockfall V. Low	Blw 6’ Blockfall V. Low	Blockfall	34’ Block-Glide Low	35’ Block-Glide Mod-High	39’ Block-Glide High	69’ Blockfall High
Beach Characteristics Soil Material Type/ Thickness Seasonal variation	Single-9’ Low	Single-10’ Low	Single Low	Single-8’ Low	Single- 3’ Low	Single- 4’ Low	Single-1’ Low	Snd/Shngl-3’ Moderate	Snd/Shngl-4’ Mod-High	Sand-6’ High	Shngle-10’ High	Shngle-1’ Low	Single-2’ Low	3-5 Torn Riprap W/ Gravel At Base Low	Single-8’ Moderate

Table 5.2-2 Coastal Profile Characteristics for Solana Beach

Prominent Location, Cross Streets	**Ocean Street**	**Cliff Street**	**Clark Street**	**Las Brisas**	**Del Mar Beach Club**
North – South Address/Block	617 Circle Dr	371 Pacific Ave	337 Pacific Ave	133 South Sierra	825 South Sierra
Reach No.	8	8	8	9	9
Topography					
Elev of Coastal Terrace	67’	78.5’	80’	84’	67’
Top Elev (height) of Bluff	65’ (46’)	77’ (51’)	80’ (55’)	87’ (59’)	65’ (37’)
Slope of Bluff-Upper/Lower	67°/37°	54°	43°	38°	78°/38°
Shape of Bluff	Complex	Flat	Flat	Concave	Concave
Top Elev (height) of Sea Cliff	19’ (10’)	26’ (21.5’)	25’ (23’)	28’ (25’)	28’ (21’)
Elev. of Beach at Sea Cliff	9.0’	4.5’	2.0’	3.0’	7.0’
Slope of Sea Cliff	Buried	90°	86°	90°	89°
Elev of Shoreline Platform	-1’	-2’	-1.5’	0.0’	-3.0’
Vegetation, Drainage, Landscape					
Plant-Type	Native	---	Native	Native	Native/Bushes
Percent Plant Coverage	5	---	80	40	30
Landscape-Structures					Mid-Bluff Wall
Geologic Formations/Structures					
Eocene-Age Geologic Formation	Torrey	Torrey	Torrey	Torrey	Torrey
Rock Type	Sandstone	Sandstone	Sandstone	Sandstone	Sandstone
Bedding					
Relative Erosion Resistance					
Fractures/Joints	Tight Joints 20’ Sea Cave	None 4’ Notch	None 6’ Notch	Tight Joints 6’ Notch	Tight Joints 15’ Sea Cave
Faults	Small Fault	None	None	None	3 faults to the south
Eocene/Quaternary Contact Elev	19’	26’	25’	28’	28’
Marine Erosion	High	High	High	High	High
Subaerial Erosion	High	None	None	None	High
Terrace Deposits					
Soil Type	SP/SM	SP/SM	SP/SM	SP/SM	SP/SM
Induration (Upper/Lower)	Poor/ Moderate	Poor/ Moderate	Poor/ Moderate	Poor/ Moderate	Poor/ Moderate
Bluff Soil Development	None	None	None	None	None
Subaerial Erosion	Low	High	Low	Low	High
Groundwater	None	None	None	None	None
Elevation					
Geologic Control – Bedrock					
Flow Rate					
Beach Characteristics					
Soil Material Type/Thickness	Sand/ Shingle	Limited Sand/Shingle	Limited Sand/Shingle	Limited Sand	Sand
Seasonal Variation					

6 IDENTIFICATION/DESCRIPTION OF REPRESENTATIVE REACHES

For purposes of this evaluation, the Encinitas and Solana Beach coastline has been divided into nine reaches on the basis of characteristics of the lower sea cliff and upper coastal bluff and offshore bathymetry. The nine reaches are as follows:

Reach No.	Identification
1	Batiquitos Lagoon to north edge of Beacons
2	Beacons to 700 block Neptune (Seawall fault)
3	700 block Neptune to Stonesteps (El Portal South)
4	Stonesteps to Moonlight Beach
5	Moonlight Beach to Swamis Stairs
6	Swamis Stairs to San Elijo Lagoon
7	San Elijo Lagoon
8	Table Tops Reef (South Cardiff) to Fletcher Cove
9	Fletcher Cove to south city boundary (Via De La Valle)

6.1 Reach 1 - Batiquitos Lagoon to North Edge of Beacons

The sea cliff along this reach of the coast is somewhat protected by a well-established shingle beach up to 10-ft thick extending 40 to 50 ft offshore. Notches generally have not developed at the base of the sea cliff and, where notches are present, they are small. Seawalls have been constructed along approximately 18 percent of this reach.

The upper bluff does not have a partially cemented cap of dune sand at the top of the bluff except in the vicinity of Profile 2. These bluffs have attained a relatively stable inclination of 28 to 38 degrees. Retreat at the top of bluff is slow after declining to the range of 33 to 35 degrees. In addition, the upper bluff surface is well protected by 60 to 95 percent vegetation cover.

6.2 Reach 2 - Beacons to 700 Block Neptune (Seawall Fault)

This 0.35-mile section of coastline represents the more slide-prone section of the Encinitas shoreline from the Beacons fault to the Seawall fault. The sea cliff in this area consists of hard siltstones and claystones, and, discounting its landslide susceptibility, is still experiencing less marine erosion than Reaches 3 and 4. The shingle beach is limited or absent in this reach. Groundwater seepage out of the cliff face is significant throughout this reach, particularly south of Beacons. Seawalls have been constructed along approximately 45 percent of this reach.

6.3 Reach 3 - 700 Block Neptune to Stonesteps (El Portal South)

This 0.50-mile-long reach has experienced the highest rate of marine erosion in Encinitas and, as a result, seawalls have been constructed along approximately 70 percent of this reach. The shingle beach is limited or absent in this reach, and notching at the sea cliff base is both significant and common. The shore platform along this reach (along with Reach 4 and the north portion of Reach 5) is lower than the remainder of Encinitas where the sea cliffs are comprised of the slightly less erosion resistant Santiago or Delmar Formations. Reaches 3 and 4 are both entirely backed by the Eocene-age cliff-forming Torrey Sandstone, and the significant marine erosion in this area, particularly from just north of El Portal to 550 Neptune Avenue, has left the upper terrace deposits at a very steep angle, locally steeper than 70 degrees where increased subaerial erosion is now expected in this area prior to any re-equilibration of the coastal bluff.

Even with these upper-bluff failures, the upper bluff has a partially cemented cap that somewhat protects the intergranular structure of the sediments in the upper bluff below. It should be noted that north of 550 Neptune Avenue, past marine erosion has been so severe as to require the construction of both lower seawalls and upper-bluff structures to protect existing bluff-top improvements. The area from 550 to 700 Neptune Avenue has, in the past, experienced the worst sea cliff retreat, with this block-and-a-half long section of coastline now completely stabilized by a variety of engineered structures. The remaining portion of this coastal reach south of 550 Neptune Avenue is almost entirely void of vegetation, a further indication of fairly recent subaerial erosion.

6.4 Reach 4 - Stonesteps to Moonlight Beach

Reach 4 is only slightly more stable than Reach 3. The coastal bluffs within this reach are also backed entirely by the more erodible bedrock type of the Torrey Sandstone. Notching at the sea cliff base is again fairly prevalent, with fairly extensive basal notches currently existing along approximately 70+ percent of this reach. Relatively low seawalls, essentially notch infills, have been constructed along approximately 10 percent of this reach. A rock revetment currently protects the south 400± ft of this reach. As with Reaches 2 and 3, the shingle beach is limited or absent in this reach, and the shore platform elevation is somewhat lower than other reaches of the Encinitas shoreline where not backed by the Torrey Sandstone cliff-forming bedrock unit. The presence of the Torrey Sandstone has, however, virtually eliminated any groundwater seepage out of the cliff face along this reach.

6.5 Reach 5 - Moonlight Beach to Swamis Stairs

This reach of the coast has a limited shingle beach subject to some notching at the base of the sea cliff. The sea cliff in the central and southern portion of this reach is comprised of the Delmar Formation, which appears to be more susceptible to block toppling along bluff-parallel joints than other formations. The toppling also appears to be promoted by groundwater seepage along the bedrock contact in the sea cliff. South of "I" Street, 30 percent of this reach has been protected by a rock revetment at the base of the sea cliff, along with dewatering wells to mitigate the effect of groundwater.

The upper bluff generally has a partially cemented cap and stands at an angle of 35 to 45 degrees. Numerous recent failures at the top of bluff have occurred in the last six years.

6.6 Reach 6 - Swamis Stairs to San Elijo Lagoon

This reach has only a narrow sand beach and a steep bluff. The bluff appears to be relatively stable in the south but becomes progressively more unstable to the north. At the north part of the reach, the CALTRANS road embankment for Pacific Coast Highway has been protected by a rock revetment at the base. Like the south two-thirds of Reach 5, the sea cliff in this reach is composed of Delmar Formation and groundwater seepage is common along the contact in the bluff.

6.7 Reach 7 - San Elijo Lagoon

San Elijo Lagoon differs from the other reaches in that a sea cliff has never been present. A wide pre-anthropogenic beach bridged the gap in the cliffs to Solana Beach, maintaining the nearly straight alignment of the coast. The coastal alignment is now established by the road fill for Pacific Coast Highway and is expected to be maintained.

6.8 Reach 8 - Table Tops Reef (South Cardiff) to Fletcher Cove

Unlike Encinitas, Reaches 8 and 9 in Solana Beach were fairly immune to significant coastal erosion prior to the 1997-98 El Niño storm season, during which approximately 830 ft, or 23 percent, of Reach 8 experienced major coastal bluff failures. By June 2000, additional collapses of overhanging notches had destabilized approximately 1,520 ft, or 43 percent, of Reach 8. By September 2001, additional collapses of overhanging notches had destabilized approximately 1,675 ft, or 47 percent, of Reach 8, again, solely the result of collapsing sea caves and notches. Since September 1998, over 30 significant cliff failures have occurred in Reach 8, all undermining and destabilizing the upper sloping terrace deposits. Reach 8 is almost entirely backed by the more erodible Torrey Sandstone, with the singular exception being the north 330 ft of Reach 8, where the more erosion-resistant Delmar Formation exists at the base of the sea cliff juxtaposed against the Torrey Sandstone by a fault, which has, in part, uplifted the oyster bed-rich Delmar Formation and responsible for Table Tops Reef immediately offshore.

This significantly accelerated sea cliff retreat affecting Reach 8 appears to have been entirely caused by the total and continued loss of the at one time relatively stable sand beach that had previously protected the Reach 8 coastal bluffs. Prior to the 1997-98 El Niño storm season, only two seawalls existed in Reach 8 below the lots at 521 Pacific Avenue and 645 Circle Drive. After the fairly significant coastal bluff erosion resulting from the 1997-98 El Niño storm season, additional 1,450± ft of seawalls and/or notch infills have now been constructed, stabilizing 4.5 percent of this reach.

6.9 Reach 9 - Fletcher Cove to South City Boundary (Via De La Valle)

Reach 9 is entirely backed by the Torrey Sandstone and represents the south edge of the study area. Although Reach 9 has recently experienced several bluff failures within the last year, it has enjoyed a slightly more protective sand beach over the last several years, in part the result of a slight concave curvature of the south Solana Beach shoreline and the presence of a small but stable headland that exists in south Solana Beach extending off the public access stairway below the Del Mar Shores condominium complex. South Cardiff State Beach is in the foreground, along with Table Tops Reef, with this perspective nicely illustrating the benefit of coastal stabilization afforded by the reef. Fletcher Cove is located in the middle of the arcuate shape, and in the background is the very minor, erosion-resistant headland just north of the south city limits that has helped to maintain a small sand fillet, enough to reduce the available wave energy impacting the sea cliffs throughout the majority of Reach 9.

Although fairly extensive basal notches also exist in Reach 9, there have been only two recent coastal bluff failures in this reach since the 1997-98 El Niño storm season. Three seawalls currently exist in Reach 9, all the result of previous sea cave collapses necessitating coastal stabilization, which combined represent approximately 550 ft, or 13 percent, of Reach 9. Additionally, existing notch infills protect approximately 500 ft, or 12 percent, of Reach 9.

7 ANALYSIS OF RETREAT OF REACHES

Retreat of the coast may occur gradually, at a relatively uniform rate, or episodically, in large increments, followed by long periods of little or no retreat. Gradual retreat is well represented by annualized retreat rates; however, the annualized rates do not adequately describe the nearly instantaneous retreat of several ft or tens of ft that may occur episodically. As used in this appendix, annualized rates include the long-term effect of episodic retreat by averaging with the intervening periods of slow retreat.

The effect of an instantaneous episode of rapid retreat is a new configuration of part of the bluff that would not have been reached for years or decades by gradual retreat. Unaffected parts of the bluff must catch up to the new configuration before the episode is likely to recur. For example, block failure along vertical bluff-parallel joints into a notch will not recur until the notch reforms and weathering loosens the next joint. In this section, the annualized rates of marine erosion of the sea cliff and subaerial erosion of the bluff top are approximately calculated, followed by estimates of episodic retreat from various mechanisms.

The analysis of retreat of reaches reflects the changes in shoreline erosion that have occurred, along with a future assessment of a no project condition having essentially a sand-barren shore platform for much of the study area. This data also reflects an evaluation of the significant photographic record provided for both Encinitas and Solana Beach, during a time when little protective beach sand existed prior to the SANDAG RSBPI project.

7.1 Slope Stability Considerations

Where marine erosion allows a fairly rapid retreat of the lower bedrock unit (primarily by blockfalls along joints and faults within the various middle Eocene-age units), the upper-bluff Pleistocene sands are undermined, causing a relatively steep to near-vertical upper bluff, more susceptible to continuous sloughing. Traditional engineering stability analyses have only limited usefulness for this type of profile, because the upper bluff terrace sands continually slough and ravel to retain a stable angle of repose (a natural geomorphic process). This natural geologic "flattening" process reduces the driving force from hypothetical failure geometry, and renders the original stability analyses invalid. Further, marine erosion at the sea cliff continues to undermine the upper bluff from the basal contact up, starting the whole process over again. From a practical standpoint, proper determination of the appropriate bluff-top setback must include an analysis of both the rate of marine erosion of the lower cliffed portion of the bluff, and of the effect of that rate in creating an "artificially" oversteepened upper bluff.

7.1.1 Surficial Sloughs and Shallow Landslides

Where residences have been constructed on the coastal bluffs information is often needed concerning surficial slope stability. The stability of slopes to remain standing steeper than 50 degrees, as measured from the horizontal surface is difficult to demonstrate under normal practice in geotechnical engineering. Soil strength used in stability analyses is primarily derived from laboratory tests of saturated soil. Saturation weakens the intergranular structure of the soil structure within the upper bluff sediments. This weakness in turn decreases the ability of the upper bluffs to stand in place at inclinations over 50 degrees. Saturation within subsurface soils of the coastal bluffs commonly occurs due to irrigation, rainfall or groundwater migration.

7.1.2 Deep-Seated Landslide

Stability of the coastal bluffs is affected by the soil strengths within and between strata that make up the various geologic units, and the height and profile of the bluff. Where these factors combine to create unstable, deep-seated conditions, landslides, such as those at Beacons and the 800 block of Neptune, may result. In these ancient landslides, the tops of the slides can cut back into the coastal terrace upwards of 60 to 80 ft in a few hours or days.

7.1.3 Bluff-Top Failures

For given values of soil strength, and assuming homogeneous conditions within the geologic units, the stability of the bluff top can be shown to be a function of the slope and the thickness of the upper terrace deposits, along with the height of a vertical scarp in the terrace deposits at the Eocene contact. The development of a vertical scarp at the base of the terrace deposits above the Eocene contact occurs subsequent to the development and collapse of a notch at the base of the sea cliff. Assuming a 45 degree upper slope inclination, the failure of a 10-foot-deep notch in the Eocene unit results in a 10-foot vertical scarp above the contact.

In order to assess the stability of the upper bluff, slope stability analyses were performed using soil strengths for the upper terrace deposits as follows:

φ = 33 degrees
c = 300 psf
γ_t = 120 pcf

A terrace thickness of 50 ft was analyzed for various slope inclinations and lower vertical scarp heights. Critical failure geometries were evaluated, specifically addressing the distance to the failure scarp from both the top-of-slope and from the face of the lower near-vertical sea cliff. Factors of safety are also shown for the various slope geometries. Recognizing that upper bluff failures propagate in much the same fashion, slope geometries exhibiting factors of safety greater than 1.25 should be viewed as unsusceptible to upper-bluff failures. Recognizing also that progressive collapse of the bluff top is episodic in nature; only those areas where relatively steep upper bluffs currently exist are susceptible to bluff-top collapses, triggered by either progressive marine erosion undermining the lower sea cliff, or from other subaerial factors.

7.1.4 Seismic Slope Instability

Potential seismic hazards for any of the bluff-top sites include ground rupture, slope instability, subsidence, seismic compaction/settlement, and ground shaking. The Cities of Encinitas and Solana Beach are located in a seismically-active area and, thus, ground shaking due to nearby and distant earthquakes should be anticipated during the 50-year design life. The closest active fault is the Rose Canyon fault, located about 2½ mi offshore of the coastline. This fault is capable of generating a Magnitude 6.9 earthquake (the maximum credible earthquake). Using deterministic seismic analysis methods, the maximum probable earthquake magnitude (defined as an earthquake magnitude with a 10 percent probability of being exceeded during a 50-year interval) is 6.5. As indicated in **Table 2.1-1**, the peak horizontal ground acceleration for the maximum credible earthquake is 0.45g and the peak horizontal ground acceleration for the maximum probable earthquake is 0.32g. However, for use in pseudo-static stability analyses, the selected seismic coefficient generally ranges between one-third and one-half of the maximum probable acceleration (USACE, 1984). Using this deterministic criteria in pseudo-static stability analyses, a horizontal acceleration of 0.1g corresponding to one-third of the value of peak ground acceleration associated with a 10 percent probability of exceedance in 50 years will result in an approximately 20 percent reduction in factor of safety. Some of the steeper slopes in Reaches 2 through 6, 8, and 9 would likely fail if subjected to seismic shaking associated with the maximum probable earthquake event. The seismically-induced failure geometry will likely be wedge-shaped, removing the outer surface of the slope and essentially flattening the slope back to a slightly gentler slope angle, with the amount of bluff-top loss, a function of the slope angle, the thickness of the terrace deposits, and the height of the vertical scarp at the base of the terrace deposits, if present. It should be recognized that seismic slope instability tends to flatten the upper sloping surface as an instantaneous event, essentially leaving the slope somewhat more stable after the loss of the outer wedge-shaped surface.

A probabilistic approach, addressing seismic slope instability and designing for the maximum probable earthquake, essentially designs for an event that has a 10 percent chance of occurrence during the 50-year design life. When addressing bluff-top retreat, one must also recognize that the bluff-top retreat rates represent a probabilistic prediction that may have a 10 to 20 percent chance of exceedance during the 50-year study period. Considering the probability of both statistically independent events occurring would result in a predicted erosion rate that would have only a 1 to 2 percent chance of exceedance during the 50-year study period. The results of the both the deterministic and probabilistic seismic analysis indicate that the likelihood (chance) of coastal bluff slope failure due to seismic causes is very low for the study area and for the 50 year life of the engineering remedies for the project. Thus the use of such seismic parameters is inappropriate for use as either a basis of engineering design or as a planning tool.

7.1.5 Upper-Bluff Erosion Model

A simple model to describe upper-bluff failures throughout Encinitas and Solana Beach is complicated for a variety of reasons, including significant changes in material type, the thickness of the upper terrace deposits, the usual presence of a highly cemented beach ridge cap, and the average inclination of the upper terrace surface. Solana Beach is considerably more uniform than Encinitas, however more tenuous due to the presence of a relic 10±-foot-thick sand beach that sits atop the Eocene cliff-forming bedrock, over which lies an ancestral dune field, with the top 6 to 10 ft capped by an iron-oxide rich, highly cemented beach ridge deposit. The geologic contact in Solana Beach ranges from about elevation 18 to 26 ft, with the average contact near elevation 25 ft. The slope of the coastal bluff-forming terrace ranges from 37 to 53 degrees (average 40 degrees), with the overlying cemented beach ridge cap often near-vertical. When examining the overall inclination from the top of the Eocene sea cliff to the top of the coastal bluff, the average inclination is on the order of 50 degrees, with an average terrace thickness in Solana Beach on the order of 55 ft.

At these relatively steep slopes, the static factor of safety is on the order of 1.1, and after the recent notch failures associated with the 1997-98 El Niño storm season, the factor of safety of the upper terrace drops to about 1.0, with the clean sands initially raveling and then failures propagating up to the top of the slope. The worst case condition measured in Solana Beach occurred at 371 Pacific Avenue, where approximately 7 ft of marine erosion, undermining the upper relatively steep terrace deposits, triggered a series of progressive upper-bluff failures that, within a period of two years, encroached approximately 16 ft back from the top of the coastal bluff. Other bluff-top failures in Solana Beach, at least as of this writing, are less advanced, with the bluff-top loss typically ranging from a few ft to 10+ ft.

The Encinitas coastline has a somewhat more homogeneous upper-bluff profile, with more cementation (cohesion) minimizing the landward extent of the often more rapid Solana Beach-type upper-bluff failures. The geologic contact elevation and thickness of the upper terrace deposits is also considerably more variable in Encinitas, with the contact elevation ranging from 15 to about 70 ft, and the thickness of the terrace ranging from 13 to 72 ft, with an average thickness of 51 ft. The slope of the upper terrace is also somewhat more variable, ranging from 35 to 55 degrees (average 43 degrees), and again, similar to Solana Beach, most of the Encinitas coastal bluff is capped by the same iron-oxide rich cemented beach ridge cap, creating an overall average inclination slightly steeper than measured along the sloping upper-bluff surface. Note that these inclinations do not reflect the fairly extensive upper-bluff failures that have impacted much of Reach 3 since the preparation of the 1996 Recon Study. It should be noted, however, that Reach 3 (the central portion of the 1996 USACE Reach 2) does appear to have eroded at or in excess of the predicted 1 foot per year, with this area currently extremely unstable and having experienced numerous upper-bluff failures, essentially advancing back the relatively steep profile.

It is also important to note that in Reach 1, north of Beacons, this area remains the most stable portion of the Encinitas shoreline, and due primarily to the more gentle overall upper-bluff slope, the growth and collapse of an 9-foot-deep notch will not immediately trigger an upper-bluff failure due to the fairly wide sacrificial section of upper bluff that still remains in this area. In other words, for upper-bluff failures to occur in Reach 1, marine erosion must advance to the point where mid-bluff failures approach the geometry of the upper-bluff profiles more typical of Reaches 3, 4, and 5 for bluff-top failures to immediately follow a sea-cliff collapse.

Given the preceding discussion, an upper-bluff failure model has been developed, which provides a reasonable nexus between sea-cliff and upper-bluff failures. This model does not address the potential for additional landsliding in Reach 2, for which there is a high probability of occurrence in the next 50 years, which may affect from 20 to 40+ ft of bluff-top improvements.

The upper bluffs in both Encinitas and Solana Beach appear to equilibrate with a modest amount of marine erosion at an upper-bluff inclination on the order of 50 degrees. This corresponds to a factor of safety on the order of 1.1, which drops to 1.0 with an 8- to 10-foot vertical scarp associated with the collapse of a notch. It appears that 8 to 10 ft of marine erosion-induced notching causes a collapse of the overhang, creating a 10±-foot vertical scarp in the upper terrace deposits, which, in Encinitas within the next few years, will propagate up the face of the bluff on those slopes at or steeper than 50 degrees. For average slope inclinations flatter than 40 degrees, no bluff-top retreat is less likely to occur; and, for slopes between 40 and 50 degrees, bluff-top failures are much more likely to occur, with average encroachments ranging from 0 to 10 ft, with the more notable upper-bluff losses occurring primarily for those slopes with average inclination approaching 50 degrees.

For the Solana Beach coastline, due to the clean relic sand deposits, upper-bluff failures may advance relatively rapidly after a basal notch failure undermines and exposes the 10-foot lower clean sand layer at the base of the geologic contact. The Monte Carlo modeling for the upper-bluff failures in Solana Beach should be consistent with the data previously provided by the Solana Beach City Lifeguards.

For the Solana Beach upper-bluff failures triggered by a basal notch failure of the sea cliff, or specifically those failures within the clean relic beach sand and overlying dune deposits, vertical scarps in the basal relic clean sands can cause from 4 to 18 ft of bluff-top retreat virtually anywhere along the Solana Beach coastline, due primarily to the relatively steep slope of the upper bluff. However, for upper-bluff failures substantially in excess of the basal marine erosion (say, for example, 16 ft), the extensive upper-bluff failure has now equilibrated somewhat, necessitating an equal amount of total marine erosion, including the initial collapse prior to again placing the upper bluff in a condition where an additional 4 to 18 ft of additional upper-bluff loss can occur. The upper-bluff failure could again trigger from 4 to 18 ft of additional bluff-top loss.

7.2 Marine Erosion of the Sea Cliff

The annualized rate of marine erosion of the sea cliff has increased over the long-term geologic rate since the sand beach was lost. The estimated rate for current marine erosion varies from as little as 0.30 foot per year for Reach 1 at the north end of the coast to as high a 1.2 ft per year for portions of Reaches 3, 8, and 9. The rate of marine erosion of the sea cliff has at least doubled along the entire Encinitas coast as a result of loss of the sand beach, and has locally increased an order of magnitude in Solana Beach. Wherever part of a reach is protected by a seawall or revetment, marine erosion of the sea cliff is arrested as long as the shore protection is maintained and was properly designed and constructed. However, where the sea cliff extends above the seawall or revetment, it will be subject to subaerial processes that will likely cause very slow retreat at a rate of approximately 0.05 foot per year. The rates are summarized in **Table 7.2-1**.

As indicated on **Table 7.2-1**, in general, predicted future sea cliff erosion rates are reported as being slightly higher than the predicted bluff-top erosion rates for the 50-year study period.

When averaged over thousands of years, sea cliff and bluff-top erosion rates will be equal. However, after say a century of storm quiescence, when the sea cliffs experience little or no erosion, the bluff top will continue to retreat as the sloping bluff matures and its slope becomes flatter. Conversely, after a period of limited storm activity, an increase in marine erosion will result in a temporary lag in bluff-top erosion due to the available (sacrificial) gentle sloping upper bluff that must now be eroded prior to again encroaching on the top of the bluff.

Historical data suggests that many years of severe coastal storm activity eroded coastal bluffs in the late 1800s. A hiatus in coastal storm activity allowed the coastal bluffs to equilibrate in the early to middle 1900s, with more severe wave energy again reported since 1980. This reduction in wave energy during the first 75± years in the 20th Century has allowed more mature, gentler slopes to develop. Thus, in predicting annualized erosion rates for the next 50 years, **Table 7.2-1** reflects a slightly higher sea cliff erosion rate to account for the recognized more mature, gently-sloping upper bluff, the retreat of which will at least temporarily lag during ongoing sea cliff erosion.

Table 7.2-1 also reflects the anthropogenic or human impacts associated with a total loss of transient beach sand, and also assumes that no beach nourishment will occur within the 50-year study period. The predicted future erosion rates assume that the more intense wave energy that has occurred in the last 25± years will continue for the next 50 years.

Variations in the rate of marine erosion of the sea cliff for the various reaches are described in greater detail below:

7.2.1 Reach 1

The low estimated rate (0.3 foot per year) for Reach 1 is primarily due to the presence of the shingle beach. This erosion rate is consistent with that reported in the Zeiser-Kling (1994) study. The erosion rate reflects a 50 percent increase above the sea level model erosion rate, acknowledging the loss of the protective sand beach, however benefit is assigned to the presence of the shingle beach. The protective shingle beach has persisted in Reach 1 largely due to the presence of a significant concrete structure near its south edge (1030 - 1048 Neptune Avenue) essentially functioning as a small stub groin, which has fairly effectively retained the updrift shingle beach, providing increased protection to all of Reach 1. A noticeable amount of this shingle beach was lost during the 1997-98 El Niño storm season, and thus the slightly increased rate of estimated marine erosion.

7.2.2 Reach 2

The central 400± ft of this reach experienced a significant landslide in June 1996, entirely unassociated with coastal erosion, excluding the fact that ongoing marine erosion has, over the years, removed a portion of the passive toe of this landslide, reducing slightly its factor of safety, and therefore at least indirectly contributing to this landslide. This 0.35-mi reach contains three active landslides, all of which appear to be fault-controlled. Discounting the landslides in this reach, the sea cliff is comprised of the relatively erosion-resistant clayey facies of the Santiago Formation. Such erosion rates are similar to Reach 1 which is not affected by landslides. Reach 2 does not have the persistent shingle beach afforded Reach 1, resulting in a slight increase in the estimated rate of marine erosion.

7.2.3 Reach 3

Reach 3 today represents the highest rate of marine erosion in Encinitas and, as a result, seawalls have been constructed along approximately 70 percent of this reach. This reach, along with Reach 4, is entirely backed by the more erodible Eocene-age cliff-forming Torrey Sandstone, and significant notching and the associated collapse of the overhang has continued to plague this reach, with numerous low-height walls having now been constructed along this reach since 1996. Significant sea-cliff and upper-bluff failures have continued to occur in this reach, resulting in upwards of 10 ft of additional marine erosion. The shore platform elevation in Reaches 3 and 4 is also lower than the other reaches in Encinitas, allowing increased wave energy propagated into the sea cliff.

7.2.4 Reach 4

Reach 4 is nearly identical to Reach 3, having the same geologic conditions and the same shore platform elevation, with its only distinction being less marine erosion than Reach 3 over the last 7 years. Significant notching exists at the base of the sea cliff in Reach 4, and several failures have also occurred in the last 7 years. However, in general, the upper bluff remains more stable in this area due to the lack of extensive lower sea cliff failures as has occurred in Reach 3.

7.2.5 Reach 5

The sea cliffs along the north third of Reach 5 are comprised of the Torrey Sandstone Formation, while the south two-thirds of the reach are comprised of the Delmar Formation. In the last 7 years, the previously relatively persistent shingle beach has been displaced. More problematic is the increase in groundwater, which has plagued the central portion of this reach where backed by the clayey impervious Delmar Formation. This section of Reach 5 also lacks the benefit of the fairly ambitious dewatering program previously instituted by the Self Realization Fellowship (SRF) church further south. The revetment fronting the coastal bluff in the vicinity of the SRF has also significantly reduced marine erosion in this area, and a sea-cliff erosion rate of 0.05 foot per year has been assigned to those areas of the bluff protected by a stable revetment. The estimated rate of marine erosion of the sea cliff in this reach north of the SRF has been increased from 0.3 foot per year to 0.6 foot per year to reflect both the loss of the at-one-time persistent shingle beach and increase in groundwater now more prevalent in the central portion of this reach.

7.2.6 Reach 6

The north-central half of Reach 6 has experienced considerable erosion in the past, necessitating the Caltrans revetment for stabilization of Pacific Coast Highway. Within the north reaches of San Elijo State Beach, past faulting in this area has substantially weakened the lower Eocene bedrock cliff-forming unit, resulting in severe erosion affecting the north 1,000 ft of the State Beach. As indicated in **Table 7.2-1**, along Reach 6, marine erosion of the sea cliff varies somewhat with the higher rates confined to the central and north sections of the State beach, portions of which have already been protected by riprap. Estimated marine erosion rates range from approximately 0.2 foot per year along the south portion of the reach, up to approximately one foot per year in the central and north portions. Only limited sand is currently present and the reach is subject to groundwater seepage along the bedrock contact. The seepage has not been mitigated by dewatering wells as has been done in the southern part of Reach 5.

7.2.7 Reach 7

No coastal bluffs exist within Reach 7. Therefore, marine erosion in this reach is limited to further beach loss.

7.2.8 Reach 8

Reach 8 has locally experienced significant erosion since the 1997-98 El Niño storm season, almost entirely as a result of a pervasive loss of its one time fairly healthy protective sand beach. Even in the summer months, since the El Niño storms, this protective sand beach has not seasonally recovered and this reach of coastline is assailed on a daily basis from waves. The shore platform elevation has been surveyed at the base of the sea cliff along this entire reach, and with the exception of the north end, the cliff-platform junction elevation is near -1 foot MSL. The Torrey Sandstone comprising the majority of the sea cliff along Reach 8 appears to exhibit some variability in its lithology, with faulting more prevalent north of Tide Park and notable variations in cementation of this Eocene cliff-forming unit existing to the south. These notable variations in cementation have allowed the formation of non-fault controlled sea caves. The growth of the sea caves is suggestive of lithologic variations in cementation, most likely associated with minor variations in its subaqueous depositional environment 45 million years ago. These variations have allowed erosion rates to locally approach 1½ ft per year adjacent to areas within the sea cliff exhibiting only one-third to one-half of these erosion rates. The north end of Reach 8, most notably the fault-controlled Table Tops Reef, has provided a modest amount of sheltering immediately to the south where estimated erosion rates, even in the absence of a protective sand beach, are on the order of 0.4 foot per year. Table Tops Reef is actually the Torrey Sandstone which has been dissected by a short length strike-slip type of fault that extends along the shoreline at the reef. The fault is mapped as inactive, which means it has moved more than 200 years ago. The faulting has caused local uplift of the reef in this reach to the point where the reef is somewhat higher than the average elevation of the wave cut platform in this reach. As a result, the reef exists as a semi-resistant erosion cap-nodule that slightly rises above the platform. Average maximum erosion rates of 1.2 ft per year have been assigned to the south portion of this reach, extending south of Tide Park down to the fault-controlled offset in the coastline at 231 Pacific Avenue.

7.2.9 Reach 9

Reach 9 is geomorphically similar to Reach 8, being entirely backed by the Torrey Sandstone. However, Reach 9 has enjoyed a slightly more protective sand beach, in part the result of a slight concave curvature of the south Solana Beach shoreline and the presence of a small stabilized headland supporting the public access stairway below the Del Mar Shores condominium complex. The north margin of Reach 9 is essentially identical to the southern margin of Reach 8, and has also locally experienced accelerated erosion in the absence of a protective sand beach, where maximum erosion rates approaching 1.2 ft per year should be anticipated in the future, assuming no additional beach renourishment projects. Near the south end of Reach 9, the sea cliff appears to enjoy the protective sand fillet that exists both upcoast and downcoast of the small stabilized headland.

Table 7.2-1 Summary of Sea Cliff and Bluff-Top Erosion

Reach	Sea Cliff (ft/yr)	Bluff-Top (ft/yr)
1	0.3	0.2
2	0.4 - 0.5	0.3 - 0.5
3	1.2	1.2
4	1.1	1.0
5	0.05 - 0.6	0.2 - 0.6
6	0.2 - 1.0	0.15 - 1.0
7	Beach, no cliff or bluff	---
8	0.4 - 1.2	0.4 - 1.2
9	0.4 - 1.2	0.4 - 1.2

Notes: 1) Erosion rates are for coastal bluffs not affected by deep-seated landsliding. Site specific geotechnical investigations might reveal susceptible areas.
2) Where a partially cemented cap of terrace deposits or dune sand exists, the subaerial erosion rate will be less.
3) Where anthropogenic activities such as foot traffic and high landscape irrigation occur, subaerial erosion may be higher.

7.3 Bluff-Top Retreat Rate

Bluff-top retreat rates are relatively dependent on retreat of the sea cliff by marine directed erosion. Along coasts of the type at Encinitas and Solana Beach, the slope decline relationship would suggest that upper bluff slopes of less than 25 degrees should develop if marine directed erosion were arrested for a thousand years. All of the upper bluff slopes throughout Encinitas and Solana Beach are significantly steeper. In general, the steeper and shorter the upper bluff, the more direct the connection in time between marine directed erosion at the sea cliff and either direct failure of the bluff top, such as within Reach 3, or accelerated bluff-top retreat, as within the other seven reaches with sea cliffs. The gradual processes of subaerial erosion combine to cause the slope of the upper bluff to decline gradually, rapidly at first and more slowly as the slope ages. Under natural conditions before the beach was lost, annualized rates of sea cliff (marine directed erosion) and bluff-top (subaerial directed erosion) retreat were approximately equal, having been in equilibrium for thousands of years. This natural rate was approximately 0.1 foot per year, for the last 6,000 years. Loss of the beach has disrupted the equilibrium, permitting an accelerated rate of sea cliff erosion, and thus a temporary lag in the annualized bluff-top retreat rate, while accelerated sea cliff retreat undermines the upper terrace deposits, eventually reaching a new accelerated equilibrium profile where both sea cliff and bluff top annualized erosion rates become equal. In general, annualized bluff-top erosion rates are somewhat less than the corresponding sea cliff erosion rates due to the apparent recent increase in sea cliff erosion and the attendant lag in propagating the effects of sea cliff retreat up to the bluff top. Reach-by-reach descriptions are provided in the following paragraphs.

7.3.1 Reach 1

The rate of bluff-top retreat along Reach 1 is estimated at 0.2 foot per year. This erosion rate recognizes that throughout Reach 1, the sloping upper bluff is relatively mature, with a relatively gentle slope capable of sustaining considerable marine-induced erosion prior to experiencing any additional bluff-top retreat. Reach 1 represents the most stable portion of the Encinitas or Solana Beach coastlines, and this is confirmed by the relatively gentle slopes of the upper bluffs in this reach.

7.3.2 Reach 2

Along this reach, future bluff-top retreat is expected to range from 0.3 to 0.5 foot per year. Some of the lag between sea-cliff and bluff-top retreat along this reach results from the fact that both the Beacons landslide and the 700 block landslide have separated the top of bluff some distance from that of the sea cliff by the physical presence of these landslides and the slope decline model does not have the immediate connection to short-term additional marine erosion. The Beacons landslide mass is less stable than the 700 block landslide, and thus has a slightly higher bluff-top erosion rate. The 800 block landslide appears to have been structurally stabilized. However, it is unclear to what extent additional upper-bluff failures may occur as the landslide backscarp equilibrates. Moreover, the actual landslide stabilization implemented by the property owners has not been reviewed and an unknown potential exists for additional landslide-related bluff-top impacts. Outside of the limits of the three landslides, marine erosion for the last several decades has created sufficient instability in the upper bluffs to enable future upper-bluff retreat to essentially match that of future marine erosion, with an estimated annualized bluff-top retreat rate of approximately 0.5 foot per year.

7.3.3 Reach 3

As with the observed marine erosion, the upper bluff along this reach has experienced significant failures in the last seven years, particularly north of North El Portal, where today much of the upper bluff has near-vertical scarps, with significant sections of the upper bluff exceeding 70 degrees inclination. The upper terrace deposits are unstable at this inclination, and significant bluff failures are anticipated to continue in order for the upper bluff to reequilibrate, even with the low seawalls now protecting a significant portion of this reach. Although seawalls have essentially eliminated all marine erosion north of North El Portal up to the northern end of Reach 3, a 400±-foot section of coastal bluff remains highly unstable, with additional upper-bluff failures expected to reduce the currently oversteepened inclination of this section of coastal bluff. The southern portion of Reach 3, although not having experienced the same level of upper-bluff failures as the northern portion, currently has extensive notching at the base of the sea cliff and in the absence of seawalls, the entire sea cliff along this remaining unprotected south portion of the reach is expected to fail, with corresponding and significant upper-bluff failures. The rate of bluff-top retreat for Reach 3, where unprotected by coastal bluff stabilization, is estimated to be 1.2 ft per year, recognizing that the upper slopes in this area are currently very steep and much of the lower sea cliff exhibits significant notching indicative of incipient failure, which would rapidly propagate up to the bluff top, with bluff-top retreat rates approaching sea-cliff retreat rates.

7.3.4 Reach 4

Reach 4 is nearly identical to the south portion of Reach 3, south of North El Portal, with significant notching and a significant potential for sea-cliff type failures immediately triggering upper-bluff type failures. Nonetheless, Reaches 3 and 4 have been subdivided, with slightly less bluff-top retreat estimated over the next 50 years due primarily to the lack of extensive lower sea-cliff failures in Reach 4 and the associated more stable upper-bluff slopes, which will provide a modest lag in estimated bluff-top retreat compared to the rate of marine erosion. The estimated rate of bluff-top retreat for the next 50 years in the absence of any stabilization measures is 1 foot per year, with the rate of sea-cliff retreat being 1.1 ft per year.

7.3.5 Reach 5

The relatively persistent shingle beach has been displaced, and with the apparent increase in groundwater along the central portion of this reach, marine erosion has increased, resulting in a corresponding increase in the estimated rate of bluff-top retreat. Although still considerably less than the Torrey Sandstone-backed Reaches 3 and 4, the north third of Reach 5 underlain by the Torrey Sandstone, along with the central portion of Reach 5, which has been adversely affected by groundwater, is expected to result in future bluff-top retreat rates approaching 0.6 foot per year in the absence of any coastal stabilization measures. South of J Street, a rock revetment protects the sea cliff and, in this area, ongoing subaerial erosion is estimated to be on the order of 0.2 foot per year.

7.3.6 Reach 6

For the central and northern portions of Reach 6, the high sea cliff, and the steep and limited height of the upper bluffs cause near immediate connection between increased sea cliff erosion and bluff-top retreat. The resulting rate of bluff-top retreat is expected to approximately equal the marine erosion rate, which in the northern 500 ft of San Elijo State Beach approaches 1 foot per year. Even where protected by revetments, pre-revetment marine erosion of the sea cliff oversteepened the upper bluff causing more rapid bluff-top retreat. Based on the present slope of the upper bluff along this reach, bluff-top retreat should range from approximately 0.15 foot per year, to as much as one foot per year (the north 500 ft of San Elijo State Beach).

7.3.7 Reach 7

No bluffs are present in this reach.

7.3.8 Reach 8

Since the 1997-98 El Niño storm season, this reach has experienced over 30 significant cliff failures, destabilizing approximately 1,675 ft, or 47 percent, of this reach, in most instances undermining and destabilizing the upper terrace deposits. During the same time period, upper-bluff failures impacting bluff-top improvements occurred at nine locations, affecting approximately 410 ft, or 12 percent of this reach, with the maximum extent of bluff-top loss extending upwards of 16 ft back from the top of the coastal bluff. Unlike the Encinitas coastline, the Solana Beach upper-bluff profile is somewhat more uniform, with an average terrace thickness on the order of 55 ft, and an upper-bluff inclination on the order of 45 degrees. With these relatively steep slopes, the static factor of safety is on the order of 1.1, and once marine erosion undermines the upper terrace deposits, the factor of safety of the upper terrace drops to about 1.0, with the clean sands initially raveling and then failures propagating up to the top of the slope. Although bluff-top failure dimensions can exceed the amount of marine erosion triggering the upper-bluff failure, on average, over the next 50 years, it is estimated that the rate of upper-bluff retreat can be no more than the rate of marine erosion, with a maximum upper-bluff retreat rate in Reach 8 approaching 1.2 ft per year, assuming no shoreline stabilization. The variability in the erosion resistance of the sea cliff within Reach 8 (and particularly at the north end of Reach 8, which is somewhat sheltered by Table Tops Reef), upper-bluff erosion within the north-most reaches is estimated to be as low as 0.4 foot per year.

7.3.9 Reach 9

Reach 9 is geomorphically similar to Reach 8, the north margin of Reach 9 is essentially identical to the south margin of Reach 8, and has also locally experienced rather significant marine and upper-bluff failures, with the most extensive upper-bluff failures occurring just south of Fletcher Cove, the Las Brisas condominium complex, and the Surfsong condominium complex just to the south. As previously noted, Reach 9 has enjoyed a slightly more protective sand beach than Reach 8 and, as a result, has experienced less upper-bluff retreat in the last five years. However, in the absence of any beach restoration projects, the majority of the protective sand beach fronting Reach 9 will also be lost in the near future, subjecting Reach 9 to the same erosive environment as Reach 8, with worst-case estimated bluff-top retreat rates approaching 1.2 ft per year in the north portion of this reach.

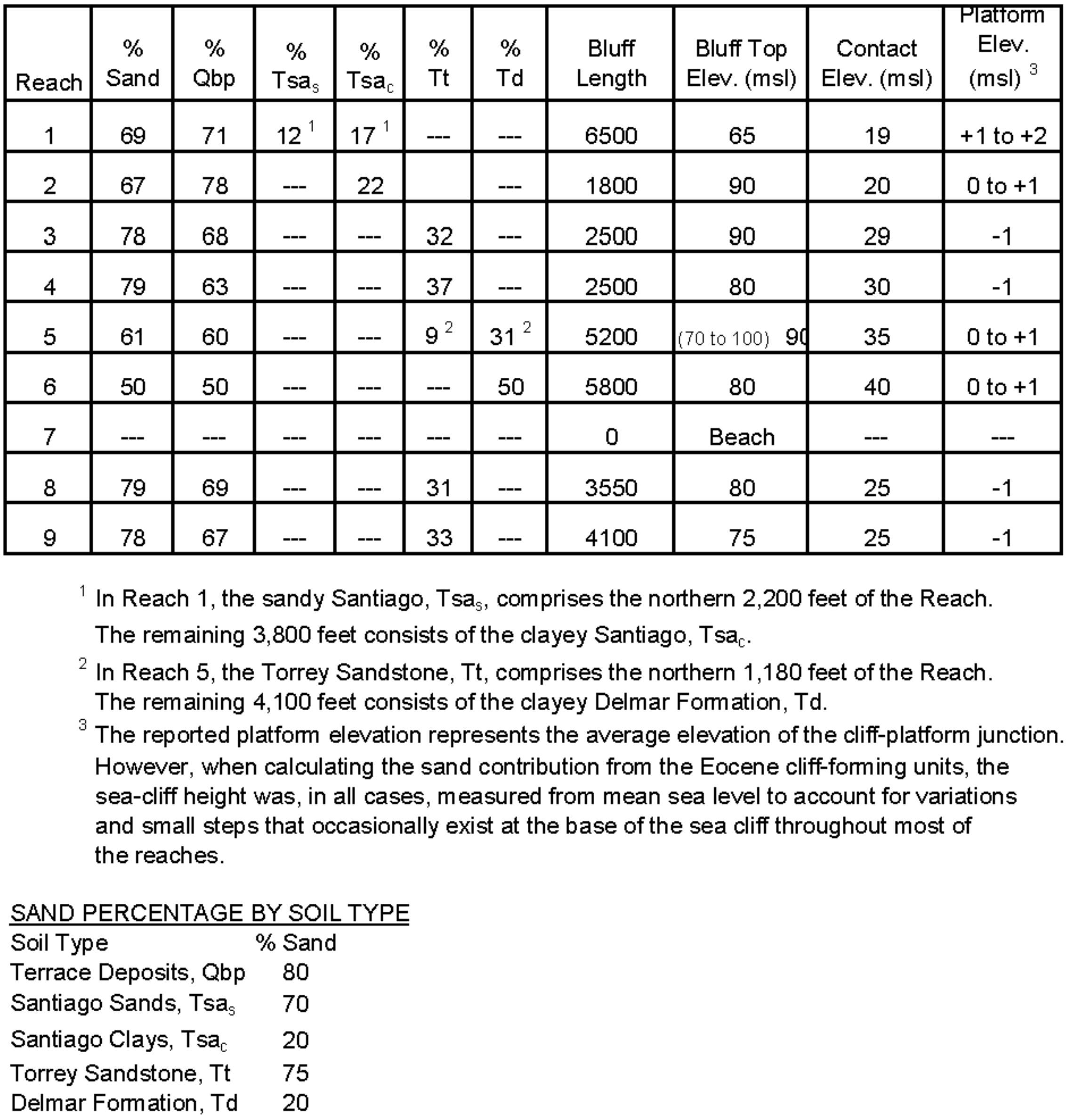
7.4 Temporal Erosion Rates

When using Dr. Sunamura's coastal erosion model, described in **Section 4.1**, to develop erosion rates from any hypothetical wave environment, temporal erosion data is required concurrent with real-time deep-water wave energy to compare the wave energy with the sea cliff's erosion resistance in order to calibrate the Sunamura model coefficients. Considerable investigative work has been conducted by Group Delta (1998, 1999, 2000) and TerraCosta (2001, 2002) in northern Solana Beach at ten locations, starting with the 1997-98 El Niño winter and extending up through 2002, which, when compared with the wave data, allows calibration of the numerical model for a given amount of recorded erosion over discrete time increments corresponding to known wave energy, both of which are necessary for model calibration.

7.5 Sand Volumes by Reach

The sediment budget estimates associated with coastal erosion, are summarized in **Table 7.5-1**. This table shows the likely percentages of sand produced from coastal erosion for the nine reaches, addressing both the Eocene cliff-forming unit and the overlying terrace deposits, and assuming that coastal erosion would advance. This table also specifically shows the estimated percentages of sand likely eroded or produced per each geologic lithological formation unit, e.g. for reach 2, the erosion of the Santiago Clay (Tsa_c) and Bay Point formation (Qbp) together produces ~ 67% sand. Also listed on **Table 7.5-1** is the approximate length of each reach, the average bluff-top elevation, and the average geologic contact elevation between the Pleistocene and Eocene units. The estimated percentage of sand produced from the coastal bluffs for each reach is explained by using reach 2 as an example. For this reach, the Qbp (Quaternary Bay Point formation) makes up about 78% of the total height of the cliff, while the (Tsa_c) Tertiary Santiago Clay, a.k.a Scripps formation) makes up the other 22 percent of the total cliff height. Thus the total cliff height (90 ft) is made up of about 70 ft Qbp and 20 ft of Tsa_c. Next, using estimated percentage of sand composition (makeup) within each formation (from notes below **Table 7.5-1**); the Qbp is about 80% sand and the Tsa_c is about 20 percent sand. Next, multiply 20 percent sand of Tsa_c by its 20 ft thickness = 4 ft; and multiply 80% sand of Qbp by its 70 ft thickness = 56 ft. Thus, the total contribution of the sandy portion is expressed as the thickness of portion of the sandy portions of these two geologic units (formations) combined. This is about 60 ft of the total 90 ft thickness of the entire height of the cliff as a whole. Finally, divide 60 ft by 90 ft, to find the percentage of this 60 ft that contributes sand from the cliff as a whole. This is approximately 67 percent, as shown in the second column from the right in **Table 7.5-1**.

Table 7.5-1 Likely Percentages of Sand Produced from Coastal Erosion



Reach	% Sand	% Qbp	% Tsa_s	% Tsa_c	% Tt	% Td	Bluff Length	Bluff Top Elev. (msl)	Contact Elev. (msl)	Platform Elev. (msl) [3]
1	69	71	12 [1]	17 [1]	---	---	6500	65	19	+1 to +2
2	67	78	---	22		---	1800	90	20	0 to +1
3	78	68	---	---	32	---	2500	90	29	-1
4	79	63	---	---	37	---	2500	80	30	-1
5	61	60	---	---	9 [2]	31 [2]	5200	(70 to 100) 9	35	0 to +1
6	50	50	---	---	---	50	5800	80	40	0 to +1
7	---	---	---	---	---	---	0	Beach	---	---
8	79	69	---	---	31	---	3550	80	25	-1
9	78	67	---	---	33	---	4100	75	25	-1

[1] In Reach 1, the sandy Santiago, Tsa_s, comprises the northern 2,200 feet of the Reach. The remaining 3,800 feet consists of the clayey Santiago, Tsa_c.

[2] In Reach 5, the Torrey Sandstone, Tt, comprises the northern 1,180 feet of the Reach. The remaining 4,100 feet consists of the clayey Delmar Formation, Td.

[3] The reported platform elevation represents the average elevation of the cliff-platform junction. However, when calculating the sand contribution from the Eocene cliff-forming units, the sea-cliff height was, in all cases, measured from mean sea level to account for variations and small steps that occasionally exist at the base of the sea cliff throughout most of the reaches.

<u>SAND PERCENTAGE BY SOIL TYPE</u>

Soil Type	% Sand
Terrace Deposits, Qbp	80
Santiago Sands, Tsa_s	70
Santiago Clays, Tsa_c	20
Torrey Sandstone, Tt	75
Delmar Formation, Td	20

8 RECEIVING BEACH AND BORROW AREAS

The section provides a summary of previous geotechnical field and laboratory investigations, recommendations for geotechnical parameters for use in design, and general geotechnical documentation for the plans and specifications. No geotechnical investigations by USACE, Los Angeles District, have been performed as part of this feasibility study. Previously existing reports and data were analyzed to make preliminary determinations as to the nature and dredgeability of sediments within the proposed offshore borrow areas and their compatibility with the sediments along the proposed receiving beach, Solana Beach-Encinitas Beach. Of special interest to this study are: (1) the type of materials to be dredged; (2) the gradation of material at the receiving beach; (3) the compatibility evaluation of the materials at the receiving beach with the potential borrow areas; and (4) the quantity of compatible sediments available within the proposed borrow areas. The overall quantities of available borrow sediment within the offshore borrow areas is based on the amount remaining as of the time of writing this report. The quantity is termed borrow capacity and is the estimated quantity of beach compatible like sediment still available. Some of the borrow capacity for some of the borrow areas will be reduced before the future beach nourishment alternatives of this project can commence because it will be removed (dredged) and used as sediment for other San Diego County beach nourishment projects, unrelated to this project.

8.1 Previous Geotechnical Investigations.

8.1.1 Nearshore/Receiving Beach Areas.

Pelagos Corporation (1990) ran 2 lines of jet probe borings along the proposed sewage outfall corridor in August, 1990. Probings were taken every 100 ft along the corridor from the shore to 2,000 ft offshore, except within the surf zone. Twenty-two probe locations were sampled and water depths were generally between 20 to 25 ft. Maximum water depths up to 35 ft.

Leighton & Associates (1991) conducted an onshore and offshore geotechnical investigation and geophysical survey from July 1990 to February 1991. This work was done to study the location for the proposed San Elijo sewage outfall. Topics studied include: sea floor topography, sediment thickness and rock outcrop areas, soil profiles, and characterization of soils. Offshore samples were taken by grab sample (14 samples), gravity core (5 samples), and vibracore (12 samples) methods. Representative samples were taken for grain size and gradation testing. A 30 line-mile multisensor geophysical survey (sidescan sonar, Geopulse sub-bottom profiler, echo sounder, and magnetometer) was also run.

Ninyo & Moore (1998) performed explorations as part of a coastal protection study at San Elijo Lagoon. Explorations included a series of test pits along the beaches, as well as two deep boreholes.

Coastal Environments (2001) ran bathymetry, sub-bottom profile, and hard substrate surveys offshore of San Elijo Lagoon in 1999. The surveys covered an area from 1,000 ft north of the lagoon inlet to 7,250 ft south of the inlet. Sand-thickness contour maps are included in the report.

Coastal Environments also surveyed 10 profiles across Cardiff State Beach in 2000. The northernmost profile crossed the beach at a point approximately 500 ft north of the San Elijo Lagoon inlet, and the southern limit of the study was about 4,000 ft south of the inlet. Sand thickness surveys were conducted along these lines by means of water-jet probings through beach sand to bedrock using a 20 foot long probe.

SANDAG RBSP II (2008). This investigation was conducted by URS in 2008, as the second part of RSBP I and went a step further to more fully identify five of the potential offshore borrow areas that were investigated previously under RBSP I. This investigation consisted of nvestigation of three additional potential borrow areas, plus a marine seismic reflection geophysical survey, and compilation of a surface seafloor surface map, showing seafloor texture and biological plant habitats

8.1.2 Offshore Borrow Areas.

California Department of Boating and Waterways (Osbourne, et al.,1983)

In 1974, a sediment and shallow structural survey of the inner continental shelf of southern California was performed by USACE's Los Angeles District Office (USACE-SPL). The objectives of the program were to characterize and map the distribution of sand deposits suitable for beach restoration and nourishment. The results of this study and additional published and unpublished reports formed the basis for Osbourne, et al. (1983). This study was a cooperative effort between numerous public and educational institutions (including USACE) to identify, locate, and characterize borrow areas for sand and gravel along the inner continental shelf of southern California. Potential borrow areas were selected using the following criteria: the deposit must lie at depths of no greater than 98 ft, the limit of economic dredging, and no shallower than 30 ft, the wave breaker zone; the areas should represent prospective sedimentary environments for sandy, low amounts of fines type sediments; the sediments should not be too indurated for dredging. Fines types of sediments are those sediments or soils that are smaller than a U.S. no. 200 engineering sieve size. Soils or sediments that pass through this sieve size are typical of clays and silts. Area V of this report covers the coastline from Oceanside to La Jolla, and includes the Solana Beach/Encinitas Study Area. Five potential borrow sites were identified, SD-III, offshore of Batiquitos Lagoon, containing up to 16.5 million cy of suitable sand; SD-IV, offshore of San Elijo Lagoon, with a maximum of 12.4 million cy of suitable sand; SD-V, offshore of San Dieguito Valley, containing a maximum of 10.3 million cy of suitable sand; and SD-VI, offshore of Soledad Valley, with up to 2.9 million cy of suitable material. Five wide-spaced vibracores were collected within the Area V coastal segment. The cores ranged from 2.3 to 9.5 ft long. Site SD-III was tested by a single vibracore hole, and the remaining four holes were not located within the identified potential borrow area sites.

Area VII of this report covers an area offshore of Mission Beach to the south of the current study area. Potential borrow site SD-IX was identified, containing a maximum of 192.0 million cy of suitable sand. However, only three vibracores were completed within, and adjacent to, site SD-IX. One of these borings contained marginally-suitable fine grained sand, and the other two possessed suitable medium grained sand.

SANDAG RBSP I (1999)

In an effort to identify borrow sources of beach compatible material offshore of San Diego County, the San Diego Association of Governments (SANDAG) instituted the San Diego Regional Beach Sand Project I. Based on a review of available historic investigations and literature review, SANDAG identified 10 possible offshore borrow sites adjacent to beaches requiring nourishment between Oceanside and the Mexican border. Potential borrow sites were selected using the following criteria: 1) the source must be located close to the beaches requiring sand nourishment; 2) the deposit must lie at depths of no greater than 24-27 meters (80-90 ft), the economic limit of offshore dredging, and no shallower than 9-15 meters (30-50 ft) of water, the "depth of closure" for seasonal bathymetric profile changes in the San Diego region; and 3) the sand must be suitable for beach replenishment based on guidelines specified by USACE. SANDAG contracted Sea Surveyor, of Benicia, California, to perform offshore surveys at each of these sites. Sea Surveyor conducted geophysical surveys using side scan sonar, a marine magnetometer, and shallow seismic sub-bottom profilers, and collected vibratory core sediment samples at the SANDAG borrow sites in January 1999. Subsamples from the cores were analyzed for lithology, grain size, and chemical constituents. These investigations included three beach compatible borrow sites near Encinitas and Solana Beaches, labeled SO-5, offshore of San Dieguito Lagoon (Site SD-V of Osbourne, et al., 1983), SO-6, offshore of San Elijo Lagoon (Site SD-IV of Osbourne, et al., 1983), and SO-7, offshore of Batiquitos Lagoon (Site SD-III of Osbourne, et al., 1983). Sea Surveyor site MB-1, located offshore of Mission Beach, (Site SD-IX of Osbourne, et al., 1983) was also explored. See Sea Surveyor (1999) for site maps, vibratory core locations, isopach maps, and sediment cross sections.

Site SO-5- is located offshore of San Dieguito Lagoon at depths of –50 to –95 ft MLLW. Previous to the Sea Surveyor investigation, no historical data was available to define the quality of beach nourishment material near Site SO-5. A geophysical survey was conducted over the site, and ten vibratory cores were drilled, ranging in penetration from 3-12 ft.

Site SO-6- is located offshore of San Elijo Lagoon at depths of -60 to –100 ft MLLW. Over 50% of site SO-6 lies at depths of -80 ft MLLW or greater.

Previous to the Sea Surveyor investigation, records for only one vibratory core could be located in the SO-6 vicinity (Osbourne, et al., 1983). The 1991 Leighton & Associates and 1990 Pelagos studies provided additional data along the southern boundary of Site SO-6.

Sea Surveyor (1999) drilled five vibratory cores within Site SO-6, ranging in penetration from 1.6 to 10.6 ft. The holes are positioned in the eastern 1/3 of the site at depths of -75 ft MLLW or less.

Site SO-7- is located offshore of Batiquitos Lagoon at depths of -50 to –100 ft MLLW. Approximately 35% of Site SO-7 lies deeper than the –80 foot contour. Available nearby historic data includes six vibratory core holes drilled by USACE (1993). Sea Surveyor (1999) completed twenty vibratory cores within Site SO-7, ranging in penetration from 1 to 15 ft.

Site MB-1- located offshore of Mission Beach, lies at depths of –60 to –110 ft MLLW. Approximately 40% of the site lies at depths greater than 80 ft. Sea Surveyor completed ten vibratory cores within Site MB-1, ranging in penetration from 9.4 to 19.3 ft.

SANDAG RBSP II (2008)

This investigation was the second part of RSBP I and went a step further to more fully identify five of the potential offshore borrow areas that were investigated previously under RBSP I. RBSP II also included investigation of three additional potential borrow areas, plus a marine seismic reflection geophysical survey, and compilation of a surface seafloor surface map, showing seafloor texture and biological plant habitats. Maps figures were prepared of these features, plus additional available features such as multibeam bathymetry, backscatter maps of the seafloor, seafloor substrate and historical kelp persistence. These maps were created using Arc Geographic Information System (ArcGIS) computer software. ArcGis is an intensive geographic data location plotting software program. This application can easily create maps of supplied vector and rastor type data. It commonly portrays or plots this information as a series of overlapping layers projected onto a common geographic reference survey system, such as Northing or Easting or Latitude and Longitude. RBSP II was conducted by URS Corporation who performed a vibratory coring investigation at eight candidate offshore borrow areas from just north of the City of Oceanside to just south of the City of Imperial Beach, California. The data is compiled by URS Corporation into a draft report, dated March 2009, titled: "Geotechnical Assessment Offshore Sand Sources Regional Beach Sand Project II San Diego County, California.

Five of the investigation areas (SO-7, SO-6, SO-5, MB-1 and SS-1) were within or near offshore borrow areas previously investigated as part of the RSPB I. The other three (TP-1 just north of Scripps Submarine Canyon, near Torrey Pines State Beach Park; ZS-1 Zuniga Shoal, located south of the entrance to San Diego Bay, near Coronado, California; and offshore of the Santa Margarita River (SM-1), just north of the Oceanside Harbor) potential borrow areas were "new" areas of investigation, although some investigations had been previously completed at these sites by others.

<u>Site SO-5 and SO-5 Del Mar borrow areas</u>- the same site as that identified in the RBSP I, except that SO-5 Del Mar is an extension of the former SO-5 site and is located closer to shore. This borrow site has since been dredged in 2001 and yielded fine grained material (silt to sandy silt, not sand) that was placed at Fletcher Cove in Solana Beach. Part of the borrow material was also placed at Torrey Pines State Beach. According to URS some of the relatively fine materials encountered during dredging may have been initially dredged from the surficial silt cover. The coarser borrow materials may have been encountered at depth. This borrow area shows up as a distinct depression in the seafloor texture map shown in the RBSP II geotechnical report (URS RBSP II 2008).

The RBSP II investigation identified SO-5 Del Mar as a potential borrow area closer to the shoreline in what is suspected to be an ancient paleochannel of the San Dieguito River. The name of the SO-5 borrow area is called out as "SO-5 Del Mar", within the latest RBSP II draft report. The marine geophysical surveys from this investigation indicate that the deepest portion of the paleochannel appears to be in the northern portion of the survey area. The sediments within the depths of the vibracores are interpreted to represent Holocene age littoral deposits. The seafloor texture appears to be sandy. The seafloor elevations at this borrow area range from -34 to -47 ft MLLW. Twelve vibracores (SO-5-201 through 211 to 213) were completed within this area (RBSP II geotechnical report).

<u>Site SO-6 and SO-6 San Elijo borrow area</u>- the same site as that identified in RBSP I, except that S0-6 San Elijo is an extension of the former S0-6 site and is slightly south and closer to shore than SO-6. SO-6 is called out as SO-6 San Elijo in the RBSP II report. This site was dredged prior to 2008 and yielded good quality coarse sand. However, continued dredging reportedly encountered some hard bottom areas. Moreover, a number of previous vibracores, located just north of SO-6, also encountered refusal atop bedrock. Based on the geophysical surveys during the RSBP II investigations, a south expansion of SO-6 was deemed likely to produce more beach compatible materials. As a result, vibracore holes were placed in this area to explore the south potential of SO-6. Eight vibracores (SO-6-201 through SO-6-207 and SO-

6-206A) were attempted within this area and were located just south of the San Elijo Lagoon outfall tunnel. Seafloor elevations of this borrow area range from -42 to -56 MLLW. SO-6 San Elijo borrow area is shown in a seafloor texture map in the RBSP II geotechnical report (URS RBSP II 2008).

<u>Site SO-7 Encinitas borrow area</u>- an extension of same site as that identified in RBSP I. The original footprint area of SO-7 was dredged of sediment borrow capacity prior to 2008, as a result this area was further explored in 2008 as part of RBSP II efforts. Six vibracores (S)-7-201 through 205) were drilled in the extension area. All of the vibracores penetrated a thin layer of sand atop a shallow, hard bedrock surface. This area was therefore deemed unfeasible as a source of offshore borrow material sediment (URS RBSP II 2008).

<u>Site MB-1 Mission Beach borrow area</u>- and extension of the same site as that identified in RBSP I. The original footprint of MB-1 was dredged somewhat of its sediment borrow capacity prior to 2008, as result this area was further explored in 2008 as part of RBSP II efforts. The area was explored over a broader area, including potential expansion of the former MB-1 borrow area to the south and towards the coast. Five vibracores (MB-201 through 205) were drilled in this extension area. All of the vibracores penetrated a thick layer of poorly graded, medium to coarse grained sand. There also appeared to be no silt cover. Thin layers of shell and gravel were also recovered within the vibracores (URS RBSP II 2008). .

<u>Site SM-1 Oceanside borrow area</u>- a new borrow site that was not previously explored by others and not part of the borrow sites identified in RBSP I. The SM-1 area is located about 2,000 to 3,000 ft closer to shore than the nearest RBSP I borrow area SO-9. The area was explored over the entire width of the modern channel and floodplain of the mouth of the Santa Margarita River.

Eleven vibracores (SM-201 to 210) were drilled in this area. All of the vibracores penetrated a thick layer of dark grey, silty fine grained sand and poorly graded fine grained sand with silt. poorly graded, medium to coarse grained sand. There also appeared to be no silt cover. Thin layers of shell and gravel were also recovered within the vibracores (URS RBSP II 2008).

8.2 <u>Grain Size (Physical) Compatibility of Sediments</u>

8.2.1 Guidelines

The USACE-SPL has established quantitative guidelines for the compatibility of dredge material to receiving beach material. A grain size distribution envelope of the receiving beach material is developed and results in a set of three curves of: the finest and coarsest limits from the 19.0 to the 0.075-millimeter (3/4 inch to U.S. #200) sieves and the average grain size curve. A composite gradation curve or individual curves are developed for each of the dredge materials borrow areas, where a composite is defined as the mean gradation of all the types of materials found in a designated borrow area. Borrow site dredge sediment is represented by a composite gradation curve and/or individual sediment samples of the boreholes (vibracores) taken within the borrow site(s). The composite gradation curves and each of those individual sample gradation curves that that plot within the limits of the receiving beach placement site envelope (beach compatibility envelope) are determined to be compatible with the receiving beach material. In addition, materials are considered compatible when: (1) Dredge material is coarser than the coarsest limit curve of the receiving beach material if not restricted by aesthetic or environmental reasons; and, (2) material passing the 0.075 millimeter (U.S. #200) sieve does <u>not</u> exceed the finest limit by a maximum of 10 percentage points.

8.2.2 Receiving Beach Sediments

The receiving beaches of Solana Beach and Encinitas are proposed as the beach fill alternatives for this study project. One grain size “envelope”, judged to be representative of both beaches, was used in the compatibility analysis. The envelope is based on a weighted average composite envelope calculated from sediment samples collected along five nearby beach profile transects. The samples were collected in 2009 by Coastal Frontiers in support of the RBSP II project. The D_{50} grain size for the receiving beaches is the diameter of 50 percent of the sediment samples and is based on the “average” curve of the envelope. This size is approximately 0.17 millimeters. The engineering description of the sediments within the envelope is poorly graded, fine grained sand with minor amounts of silt.

8.2.3 Offshore Borrow Areas

The 1999 SANDAG investigations identified three beach compatible borrow sites near Encinitas and Solana Beaches, labeled SO-5, offshore of San Dieguito Lagoon, SO-6, offshore of San Elijo Lagoon, and SO-7, offshore of Batiquitos Lagoon. Another borrow site located offshore of Mission Beach, Site MB-1, was also identified. Sea Surveyor (1999) collected vibratory core sediment samples at the SANDAG borrow sites in January 1999. Subsamples from the cores were analyzed for grain size. Sediments from borrow sites SO-5, SO-6, and SO-7 had silt-clay concentrations that ranged from 0 to 20 percent, and mean grain size diameters ranged from 0.10 to 0.88 millimeters (fine to medium grained sand). Sediments from borrow site MB-1 had silt-clay concentrations that ranged from 0 to 32 percent, and mean grain size diameters ranged from 0.09 to 0.74 millimeters (fine to medium grained sand). The areas around all of these sites were investigated again in 2008 by URS on behalf of SANDAG, as mentioned in section 4.2.2, above.

Borrow area SO-7 was dredge of capacity after 1999 and was explored again in 2008 (RBSP II). Much of this area was recently explored beyond the former limits and was found to contain shallow bedrock with no appreciable layers of compatible borrow site sediments. Therefore this site is no longer described or mentioned for consideration as a borrow source for this study project.

8.3 <u>Grain Size Analysis and Compatibility of Select Offshore Borrow Sites</u>

The section of the report provides geotechnical analysis of beach compatibility based on select offshore borrows sites in the vicinity of the study project. This analysis is specifically based on recent geotechnical data obtained from existing and previously identified offshore borrow sites and nearby receiving beach grain size profiles. Each potential borrow site has been analyzed for grain size compatibility for comparison of four receiving beach transect profiles chosen by the SANDAG for their proposed beach nourishment (fill) alternatives for beaches in San Diego County. Such transects represent four of the nine regional receiving beaches selected by SANDAG for nourishment as part of the RBSP II and do not specifically include Encinitas or Solana Beach beaches. However, some of these transect profiles are in the vicinity of the beaches identified in the study area.

This analysis consists of beach compatibility grain size analysis for four selected offshore borrow sites from the eight listed RBSP II sites (SM-1 Oceanside, SO-6 San Elijo, SO-5 Del Mar and MB-1 Mission Beach); beach compatibility grain size analysis for one selected offshore borrow site previously recognized from the USACE San Clemente Study (USACE Borrow Area No. 2); and discussion of dredging costs; and volume and description of the beach compatible sediment at each of the five borrow sites. In summary, the five selected borrow sites include four of the SANDAG sites and the one USACE Borrow Area No. 2 which is adjacent to SANDAG site SM-1. For purposes of this beach compatibility analysis Borrow Area No. 2 and SM-1 are combined as one borrow site.

The six sites analyzed herein are MB-1, SO-6, SO-5, SM-1 and Corps of Engineers Borrow Area No. 2. Borrow site SO-7 was dredged in 2001 by SANDAG as a part of their beach nourishment efforts and is no longer considered feasible as a borrow site for this study project. The current analysis includes the addition of SANDAG borrow site SM-1 and Corps of Engineers Borrow Site No. 2, which were not previously analyzed. The analysis of the four SANDAG sites is based on the latest geotechnical information gathered from the RBSP II Moffat & Nichol and Coastal Frontiers work and the URS geotechnical report. The analysis performed for Corps of Engineers Borrow Site No. 2. is based on <u>older</u> USACE-SPL geotechnical data. This particular borrow site was discovered in 2003 during the USACE-SPL geotechnical investigation of sand sources in support of the USACE-SPL San Clemente Feasibility Study. Site No. 2 has already been designated by the USACE as a compatible source of offshore material for beach fill for that particular project.

The latest geotechnical work on the offshore borrow sites was completed by the (SANDAG) as part of their RBSP II study efforts. Eight offshore borrow sites investigated were SM-1 Oceanside, SO-7 Encinitas, SO-6 San Elijo, SO-5 Del Mar, TP-1 Torrey Pines, MB-1 Mission Beach, ZS-1 Zuniga Shoal and SS-1 Imperial Beach. This work was essentially an additional geotechnical investigation and update of the same borrow sites previously identified in the RBSP I geotechnical work effort. SANDAG hired a commercial engineering consulting firm of Moffatt & Nichol Engineers Inc. to perform and manage this newest work. The actual offshore borrow site geotechnical work was sub-contracted by Moffatt & Nichol to URS Incorporated, a separate engineering consulting firm. This work is available and published within a separate final engineering report, titled *"Geotechnical Assessment Offshore Sand Sources Regional Beach Sand Project II, San Diego County, California",* dated March 2009. Moffatt & Nichol also sub-contracted additional geotechnical work on RBSP II to another engineering firm, Coastal Frontiers Corporation. Their work involved collection, testing and reporting of sediment grain size along <u>nine</u> beach profile transects between Oceanside and Imperial Beach. These transects were selected to be representative of the <u>nine</u> beaches selected by SANDAG for proposed nourishment by dredged fill from offshore borrow sites as identified in the RBSP II Geotechnical Report.

8.3.1 Results of borrow site beach compatibility analysis

The grain size compatibility analysis was made according to USACE-SPL Geotechnical Branch office guidelines. These guidelines are the same as those written within the SCOUP (Sand Compatibility and Opportunistic Use Program). The USACE-SPL analysis is based on calculating the natural beach compatibility envelope of three gradation curves for the project study beach placement sites at Solana Beach and Encinitas beaches. The beach placement sites are based on the five beach transects that were sampled as part of the 2009 RBSP II efforts. These grain size curves are shown drawn as a final set of grain size curve envelopes representing all five transects and are commonly known as the "beach compatibility envelope". These envelopes of curves are labeled "fine limit", "coarse limit" and "average". Once this is done, the weighted average grain size curve of each individual borrow area-site sediment vibratory core sample are matched to see where they fit within the envelope. For this analysis there is one set of three beach grain size curve envelopes. This set represents the grain size envelope for all five sampled beach transects. The five transects were chosen because they are the closest transects to the actual beach fill placement sites of Solana Beach and Encinitas. Three of the five offshore borrow areas (S0-5, S0-6 and MB-1) were analyzed for grain size placement compatibility based on the weighted average of the individual vibratory borehole core sample gradation test results for these areas. Two of the five offshore borrow areas (USACE Borrow Area No. 2 and SM-1), were combined as one borrow site for the purposes of beach compatibility analysis. Their analysis was based on the grain size average as a whole (composite) of the U.S. no. 200 sieve each of the vibratory boreholes for each of these two combined areas.

These USACE-SPL guidelines specify that individual sediment samples collected from each borrow area footprint area and/or the composite gradation curve for the overall borrow area can be no more than 10% above the finest limit gradation curve of the beach fill or placement area. The finest limit curve is one of the three curves representing the overall composite grain size gradation of the weighted average calculated profile or "beach compatibility envelope" of the placement area(s). The compatibility envelope is based on the weighted average of the finest, coarsest and average grain sizes from the individual beach transect-profile samples. For the beach profile samples, the weighted average is calculated as a composite according to the number of transect profiles for each beach, e.g. for a two transect profile per beach, the weighted average would be a composite of these two profiles and would result in three curves of average, fine and coarse. For individual vibracore samples, the weighted average gradation curve itself is calculated based on the total length of the sample in relation to the length of each different lithologic sediment layer, e.g. a 10 foot long vibracore sample with 2 different lithologic sediment layers of 5 ft length would have a weighted average gradation based on the 2 lengths compared to the overall 10 ft total length. The "finest limit" gradation is based on a sample for a U.S. Sieve size no. 200 (0.075 mm) result. The guidelines also specify that the dredged sediment can be greater than the "coarsest limit" placement profile sample grain size composite curve, as long as aesthetic quality of the dredged sediment in this coarser size range is acceptable. As shown on figures of Part A, "Borrow Area Compatibility Curves", the composite gradations of borrow sites SM-1, SO-5, SO-6, and MB-1 all meet or exceed the guidelines. Additionally, the no. 200 sieve percent fines average from COE Area No. 2 falls well below the 14 percent fines content of the receiving beach envelope. Specific results of the analysis are summarized as follows:

<u>SO-5-Del Mar</u>

SO-5 is located approximately 1,800 ft offshore of Del Mar racetrack and across the mouth of the San Dieguito River, where it intersects the Pacific Ocean. It is also the closest of the five borrow sites to the Solana Beach receiving beach site and is approximately 1,800 ft offshore of this beach. SO-5 consists of a grey to yellowish brown, poorly graded, fine to medium grained sand.

A SANDAG RBSPI (1999) geophysical survey conducted over the site indicated the presence of medium to coarse grained sediment in a prism measuring 2-5 ft thick along the eastern boundary, increasing to 25 ft along the western boundary. To confirm the geophysical study, ten vibratory cores were drilled, ranging in penetration from 3-12 ft. Results of the grain size analysis showed that the majority of the drilled portion of site SO-5 was suitable sand for beach nourishment. This material is predominately gray to olive gray fine-grained sand (median grain size of 0.14 mm) with 3% silt content.

For the SANDAG RBSPII (2008) project, SO-5 was reinvestigated beyond its former borrow site limits and sediment borrow material recovered from the vibracores was described as a grey to yellowish brown, poorly graded fine to medium grained sand. Based on this data, there appears to be essentially no silt cover. Thin layers of shell and gravel were also recovered in some of the vibracores. The average grain size distribution for the borrow area has an approximate D_{50} of 0.35mm (fine grained sand), with a fines content of 5 percent. This average is (coarser) approximately 2 times the D_{50} size of nearby receiving beaches (represented by the four nearest 2009 beach transect profiles) that have an average D_{50} of approximately 0.17mm (fine grained sand) and consist of coarser materials. All individual vibratory core samples fit well within the grain size compatibility envelopes for Solana Beach and Encinitas. The ten cores analyzed were all collected to a depth of approximately 20 ft. The no. 200 sieve grain size of all the cores is below 10%. This is below the 14% finest curve shown on the envelope curves.

SO-6 San Elijo

SO-6 is located approximately 1,500 ft offshore of the San Elijo Lagoon and approximately 4,500 ft north of the Solana Beach receiving beach site. SO-6 consists of a grey to yellowish brown, poorly graded, fine to medium grained sand (0.065 to 2mm diameter).

Marginally-acceptable fine-grained sand was reported by Osbourne, et al. (1983) in one vibratory core drilled in the SO-6 vicinity. Pelagos (1990) ran 2 lines of jet probe borings along the proposed San Elijo outfall corridor which bounds the site on the south. The predominant material logged was fine to medium sand (0.065 to 2mm diameter).

Sea Surveyor (1999) for SANDAG RBSPI drilled five vibratory cores, ranging in penetration from 1.6-10.6 ft. The holes are positioned in the eastern 1/3 of the site at depths of -75 ft MLLW or less. The two holes in the northern third of the site collected about 4 ft of very fine sand overlying bedrock. The two cores within the east-central portion collected 1.6 ft of medium grained sand overlying bedrock, and the southernmost hole, located approximately 1,000 ft north of the San Elijo Outfall, and collected 10.6 ft of suitable sand. Results of the grain size analysis showed that the median grain size of potential borrow site SO-6 is 0.34 mm (fine grained sand), and that majority of the drilled portion of the site was suitable sand for beach nourishment.

Results from SANDAG RBSPII (2008) investigation showed previous dredging of this area encountered some hard bottom. SO-6 is located within the offshore paleochannel of Encina Creek. The deepest portions of the paleochannel are thought to be along the southern margins of the modern lagoon (URS, RBSP II). The sediments are thought to represent Holocene beach deposits. The sediment borrow material recovered from the vibracores is described as a grey to yellowish brown, poorly graded fine to medium grained sand (0.065 to 2mm diameter). Based on this data, there appears to be essentially no silt (less than 0,075mm diameter) cover. Thin layers of shell and gravel were also recovered in some of the vibracores. The average grain size distribution for the borrow area has an approximate D_{50} of 0.35mm (fine grained sand), with a fines content of 5 percent. This average is (coarser) approximately 2 times the D_{50} size of nearby receiving beaches (represented by the four nearest 2009 beach transect profiles) that have an average D_{50} of approximately 0.17mm (fine grained sand) and consist of coarser materials.

All individual vibratory core samples fit well within the grain size compatibility envelopes for Solana Beach and Encinitas. The five cores analyzed were all collected to a depth of approximately 20 ft. The no. 200 sieve grain size of all the cores is below 10%. This is below the 14% finest curve shown on the envelope curves.

MB-1, Mission Beach-

MB-1 is located approximately 3,500 ft offshore of Mission Beach and approximately 2,500 north of the Mission Bay navigation entrance channel. MB-1 consists of a brownish yellow, poorly graded, medium to coarse grained sand.

All individual vibratory core samples collected from MB-1 during the RBSP II geotechnical investigation fit well within the grain size compatibility envelopes for Solana Beach and Encinitas. The ten cores analyzed were all collected to a depth of approximately 20 ft. Five of the ten cores were collected during the RBSP I geotechnical investigation. The no. 200 sieve grain size of all the cores is below 10%. This is below the 14% finest curve shown on the envelope curves.

Site MB-1 results SANDAG RBSP I (1999)

Of the three vibratory core holes reported by Osbourne, et al. (1983) in the MB-1 vicinity, one contained marginally-suitable fine grained sand, and the other two possessed suitable medium grained sand (0.4 to 2mm diameter).

Sea Surveyor (1999) drilled ten vibratory cores, ranging in penetration from 2.9-5.9 meters (9.4-19.3 ft). Site MB-1 contains a thick layer of medium- to coarse-grained sand (0,4 to 5mm diameter) covering the entire area and varying in thickness from approximately 4.6 to 18.3 meters (15 ft to 60 ft). The sand is a unique golden or red-brown color, due to a somewhat higher than average proportion of feldspar and lithic fragments. The geophysical survey and one vibratory core hole indicated that the northeast corner of the site has a 0.6 meter (2 foot) layer of silty material lying on top of the sand. Results of the grain size analysis showed that the majority of the drilled portion of Site MB-1 contains fine- to coarse-grained sand (2 to 5mm diameter) that is suitable for beach nourishment. The material is predominately medium-grained sand (median grain size of 0.52 mm) with 0.9 % silt content, and a 0.9 % gravel component.

Site MB-1 Mission Beach results SANDAG RBSP II (2008)

This area was dredged after 1999 and yielded good quality coarse to medium grained sand (. The five vibracores drilled in this area recovered poorly graded, medium to coarse grained sand (URS RBSP II). The average grain size distribution for the borrow area has an approximate D_{50} of 0.51mm (medium grained sand), with a fines content of 2 percent. This average is (coarser) approximately 3 times the D_{50} size of nearby receiving beaches (represented by the four nearest 2009 beach transect profiles) that have an average D_{50} of approximately 0.17mm (fine grained sand) and consist of coarser materials (see Addendum).

SM-1 and Borrow Site No.2-

SM-1 and Borrow Site No. 2 is located approximately 1,400 ft offshore of navigation entrance channel to Oceanside Harbor. These two borrow sites are the farthest sites from the receiving beaches. SM-1 (yellow box only)- consists of a dark gray mix of poorly graded silty fine grained sand and fine grained sand (0.065 to 0.4mm diameter). Corps Borrow Site No. 2- consists of a brownish poorly graded, fine to medium grained sand (0,065 to 2mm diameter) with occasional gravels at deeper depths, scattered throughout the borrow site. The gravels occur in lenses of approximately 3 ft.

The grain size passing the no. 200 for all individual vibratory core samples collected from SM-1 during the RBSP II geotechnical investigation fit well within the grain size compatibility envelopes for Solana and Encinitas beaches. The four cores analyzed were all collected to a depth of approximately 20 ft. The rest of the cores analyzed were collected during earlier geotechnical investigations of the borrow sites related to the SANDAG RBSP I study and the Corps of Engineers San Clemente study. Approximately forty five cores were analyzed and collected to an average depth of 15 ft. A total of approximately fifty cores were analyzed from these two study efforts from within the two borrow site boundaries. The weighted average composite no. 200 sieve grain size of all the fifty cores is below 10%. This is below the 14% finest curve shown on the envelope curves.

SM-1 was investigated as a new offshore borrow site as part of the RBSP II efforts. Borrow site No. 2 was previously identified as a source of offshore borrow material sediments for the Corps of Engineers San Clemente study project. Neither of these areas has yet been dredged as a source of beach replenishment material. The average grain size distribution for the borrow area has an approximate D_{50} of 0.22mm (fine grained sand), with a fines content of 5 percent. This average is (coarser) approximately 2 times the D_{50} size of nearby receiving beaches (represented by the four nearest 2009 beach transect profiles) that have an average D_{50} of approximately 0.17mm (fine grained sand) and consist of coarser materials (see Addendum).

8.3.2 Borrow site grain size and volume analysis

The individual grain size curves for vibratory cores at three of the five selected offshore borrow sites, SO-5, SO-6 and MB-1 fit well within the overall grain size envelope for the beaches between Carlsbad and San Elijo Lagoon. The weighted average composite grain size passing the no. 200 sieve for the two offshore borrow sites (one combined), SM-1 and Corps Borrow Site No. 2 fit as a point well within the same envelope.

The average **50 percentile (D_{50})** grain size for the five borrow sites is as follows:

- SO-6 is approximately **0.35** millimeters (fine grained sand) = D_{50}.
- SO-5 is approximately **0.59** millimeters (medium grained sand) = D_{50}.
- MB-1 is approximately **0.51** millimeters (medium grained sand) = D_{50}.
- SM-1 and Borrow Site No. 2 combined is approximately **0.23** millimeters (fine grained sand) = D_{50}.
-

The volumes of sediment currently available from each of the five offshore borrow sites is as follows:

<u>SO-5</u>

The volume of currently available sediment is approximately 8,800,000 cy. Approximately 990,000 cy of this sediment is proposed to be removed in the near future as part of the RBSP II beach nourishment efforts. A total of approximately 7,810,000 cy is potentially available from this site, if dredged to a total depth of 20 ft. This is an increase above the RBSP II estimate based on the same depth. The RBSP II estimate is approximately 3,851,852 cy. The extra volume is a result of extending the borrow area to the northwest (Figure 2, Part B).

SO-6

The volume of currently available sediment is approximately 2,500,000 cy. Approximately 645,000 cy of this sediment is proposed to be removed in the near future as part of the RBSP II beach nourishment efforts. A total of approximately 1,855,000 cy is potentially available from this site, if dredged to a total depth of 20 ft. This is an increase above the RBSP II estimate based on the same depth. The RBSP II estimate is approximately 1,316,667 cy. The extra volume is a result of extending the borrow area towards the shoreline but still within the closure depth (Figure 2, Part B).

MB-1

The volume of currently available sediment is approximately 6,500,000 cy. Approximately 650,000 cy of this sediment is proposed to be removed in the near future as part of the RBSP II beach nourishment efforts. A total of approximately 5,850,000 cy is potentially available from this site, if dredged to a total depth of 20 ft. This is an increase above the RBSP II volume estimate based on the same depth. The RBSP II estimate is approximately 3,300,000 cy. The extra volume is a result of extending the borrow area towards the ocean and north of the previous dredged out depression (Figure 3, Part B).

SM-1 and Borrow Area No. 2

The volume of currently available sediment is approximately 23,280,000 cy from these two borrow sites combined. None of this sediment is proposed to be removed in the near future as part of the RBSP II beach nourishment efforts. A total of approximately 23,280,000 cy is potentially available from this site, if dredged to a total depth of 15 ft. This is an increase above the volume according to the RBSP II geotechnical data for just the SM-1 borrow site alone. The RBSP II estimate for SM-1 alone is approximately 7,864,722 cy based on a potential dredge depth of 20 ft. This amount is incorrect and misleading and represents the entire SM-1 borrow site limits as calculated for volume. For this analysis, only a small portion of SM-1 is calculated in the volume analysis for these two borrow sites. This portion exists outside these limits and is shown as the yellow box (Figure 4, Part B). The extra volume for Borrow Site No. 2 is a result of adding Borrow Site No. 2 to part of the SM-1 site and combining them both into one large borrow site (Figure 4, Part B). Most of SM-1 already fit well within the previous limits already established for site No. 2 and was not included in the volume calculation.

The extra volume of sediment gained from borrow areas SM-1, SO-6 and SO-5 is assumed to exist from an extended area at each site that has not yet been geotechnically explored. Additional geotechnical exploration of sediment within each of these extended areas would need to be accomplished in order to confirm its characteristics and physical compatibility to the project study beach fill placement areas.

8.3.3 Summary

Five borrow sites (USACE Borrow Area No. 2 and SM-1 were combined as one borrow site) were analyzed for beach compatibility with the receiving beaches of Solana Beach and Encinitas. This analysis was based on the latest grain size and geotechnical data from the RBSP II efforts and additional but older data from the Corp of Engineers offshore Borrow Area No. 2. The receiving beach profile (beach compatibility envelope) is derived from the 2009 SANDAG RBSP II Coastal Frontiers beach profile sediment grain size data. Coastal Frontiers collected grab samples at every 6-ft in elevation change between +12 and -30 MLLW from nine transect locations between Oceanside and Imperial Beach. Select data from five sampling transects between Ponto Beach and San Elijo was used to create a composite gradation envelope judged to be representative of both Solana Beach and Encinitas beaches. Samples collected at +12 and -30 MLLW were not all representative of normal beach sorting processes and were not included in the analysis. Samples have been not collected specifically at Solana Beach and Encinitas receiving beaches, however, beach profiles sampled both up coast and down coast from the project sites display almost identical envelopes with maximum fines (silt and clay) content between 1 and 12 percent. The grain size analysis was conducted according to Los Angeles District U.S. Army Corps of Engineers (LADCE) Geotechnical Branch office guidelines. These guidelines are the same as the 2006 SANDAG SCOUP (Sand Compatibility and Opportunistic Use Program) guidelines.

The beach or placement compatibility grain size “envelope” is drawn as a set of three curves. The “coarse” and “fine” limits are composite curves based on respectively the minimum and maximum percent passing each sieve size from any of the five profile samples. The “average” curve is the mean of all thirty samples collected from the five profiles. The same envelope is used for all five borrow sites in the analysis. The transects are plotted on a small scale map, as shown on Figure 1, Part B of this Addendum. This map shows their locations relative to the overall project study area.

The USACE-SPL analysis compared the weighted average grain size curve of sediments contained within the borrow sites to the composite grain size envelope for the receiving beaches as described above. The borrow site sediment grain size curves are based on actual down-hole sediment samples collected by vibratory core methods of sampling. Using the vibra-core data, the weighted average of the borrow site sediments (fill) was calculated for the three sites of SO-5, SO-6 and MB-1. A weighted average grain size curve was not calculated for Borrow Site No. 2 and SM-1 combined, because of the voluminous amount of vibra-core data available. As a result, the vibra-core sediment data for this site was reduced to selection of the weighted average sediment grain size passing the U.S. no. 200 sieve for each and all of the individual vibra-core samples collected for this combined borrow site.

The resulting beach compatibility curves show the fit and shape of the individual weighted average curves for only borrow areas SM-1, SO-5, SO-6 and MB-1. The curves for USACE Borrow No. 2 and SM-1 sites combined are not plotted but instead are shown as a point (dot), representing the weighted average of each of the vibra-core sample results collected with these borrow areas for the U.S. no. 200 sieve size.

8.4 Chemical Compatibility of Sediments.

8.4.1 Receiving Beach Sediments

The chemical characteristics of the sediments are summarized in Section 4.3.1.5 of the Encinitas and Solana Beach Beach/San Elijo Lagoon EIR (MEC, 2002). Total organic carbon concentrations ranged from 0.05 to 0.06 percent. Contaminant concentrations of metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc), pesticides, PCBs, PAHs, and phenols were non-detectible to low, and contaminant concentrations were below ER-L and ER-M concentrations.

8.4.2 Offshore Borrow Areas

Sea Surveyor (1999) collected vibratory core sediment samples at SANDAG borrow sites for the San Diego Regional Sand Project in January 1999. Sediments were composited from the full length of each vibracore collected within each borrow site into a single sample for chemical analysis. The chemical characteristics of the sediments are summarized in Section 4.3.1.5 of the Encinitas and Solana Beach Beach/San Elijo Lagoon EIR (MEC, 2002). Total organic carbon concentrations ranged from 0.04 to 0.10 percent. Contaminant concentrations of metals, pesticides, PCBs, PAHs, and phenols were non-detectible to low, and contaminant concentrations were below ER-L and ER-M concentrations.

8.5 Sediment Volume Analysis for Offshore Borrow Sites.

Sediment volume analysis for the offshore borrow sites is explained within the Addendum to this appendix.

8.6 Dredgeability.

Site SO-5

The site contains a thick deposit of fine to medium grained sand (0.065 to 2 mm diameter). This area was previously dredged and yielded suitable material with fine materials encountered during upper layers dredged, followed by coarser layers near the end of the dredge depths.

Site SO-6

The site contains a relatively thick deposit of very fine to medium-grained sand (0.065 to 2mm diameter), resting on shale bedrock and is suitable for beach nourishment. This area was previously dredged and yielded good quality coarse sand (2 to 5 mm diameter0, but continued dredging did encounter some hard bottom on bedrock.

Site MB-1

The borrow area contains a thick deposit of medium- to coarse-grained sand (0.4 to 2 mm diameter) covering the entire area and is suitable for beach nourishment. This area was previously dredged and yielded good quality coarse sand of extensive thickness.

Site SM-1 and USACE Borrow Area No. 2

The borrow area contains thick deposits of mostly fine to medium grained sand (0.065 to 2 mm diameter0, with relatively thick layers of gravel and some cobble. This area has never been dredged.

8.7 Previous Dredging and Nourishment Activities.

Beach nourishment efforts have been instituted at several locations within the study area. These nourishment efforts have resulted in the placement of approximately 783,200 cy of sand along the Encinitas/Solana Beach shoreline to date. The replenishment includes the regular sand-bypassing at Batiquitos Lagoon since 1998, annually imported material at Moonlight

Beach for the past ten years, an opportunistic sand placement at Fletcher Cove, and the 2001 SANDAG sand project.

In 1997, the Batiquitos Lagoon Enhancement Project was completed in order to restore the natural lagoon habitat. As a result of on-going maintenance efforts within the lagoon in support of the initial project, approximately 122,150 cy of sand have been placed downcoast at Batiquitos Beach.

A number of smaller scale localized nourishment projects have also been performed within the study area. The City of Encinitas provides an annual beach replenishment of approximately 1,000 cy to Moonlight Beach each spring and the mouth of the San Elijo Lagoon is periodically dredged to maintain adequate tidal flushing on an as-needed basis. Since October 1986, San Elijo Lagoon has supplied an approximate average annual sediment volume of 14,860 cubic yard to the immediate downcoast adjacent shoreline. In addition, in the spring of 1999, approximately 51,000 cubic yard of sand was placed at Fletcher Cove as a result of the Lomas Santa Fe Grade Separation Project (AMEC, 2002).

The San Diego Association of Governments (SANDAG) Regional Beach Sand Project, performed during the summer of 2001, resulted in the placement of approximately 600,138 cy of beach nourishment sands at 5 different beach locations within the Encinitas and Solana Beach project study area. Although total volumes of 972,249 cy of sand were dredged from borrow site SO-7, and 102,400 cy were dredged from borrow site SO-6, to replenish the beach areas located within the Cities of Oceanside, Carlsbad, and Encinitas.

In addition to the above-mentioned sites, SANDAG also dredged a volume of sand from borrow site MB-1 to replenish local beach areas.

8.8 Conclusions

The sediment fill within all of the five offshore borrow sites is compatible for the receiving beach based on grain size analysis alone and according to the USACE-SPL guidelines for beach compatibility analysis.

Approximately 10 million cy total of sediment fill is needed to fulfill the NED (National Economic Development) plan for the Solana Beach-Encinitas study project. Some of this volume may be available from the nearest borrow areas to the receiving beaches. The nearest borrow areas are SO-5 and SO-6. Approximately 9 million cy of sediment may be available from both of these sites even after they are dredged during future RBSP II nourishment activities. This volume is based on a total dredge depth of 20 ft.

8.9 Recommendations.

- Update the cost estimate for dredging, if not already done, for all five borrow sites, particularly SM-1 and Borrow Site No. 2.

- Additional sediment samples along beach transect profiles should be collected to determine more accurate and representative gradation sizes of the receiving beach sites. This should occur in the near future. These transects should be located perpendicular and directly across both of the beaches at Solana Beach and Encinitas. Four total transects should be sampled along two profile lines at each beach. The current receiving beach envelope shown and calculated is approximate because it is only a weighted average composite of the entire beach along the coast from Pontos Beach to San Elijo.

- The 2009 Coastal Frontiers beach transect profiles are a good set of sediment sample data because they were collected along a wide range of elevations above and below 0 ft MLLW. The 2009 profile transects are indicative of the actual existing onshore and nearshore beach sediments and are the most representative of the receiving beach according to the LADCE beach compatibility guidelines. The same type of profile sample collection activity should be initiated along transects located perpendicular to the two receiving beach fill sites of Solana Beach and Encinitas in the fashion mentioned above.

- Information and assumptions for the SANDAG borrow areas are generally based on an insufficient number of exploratory borings. The number of samples in each area should be based on the LADCE guidelines (the square root of the area in square yards divided by 50). Therefore it is recommended to conduct an additional geotechnical supplemental investigation in each of the proposed SANDAG borrow areas.

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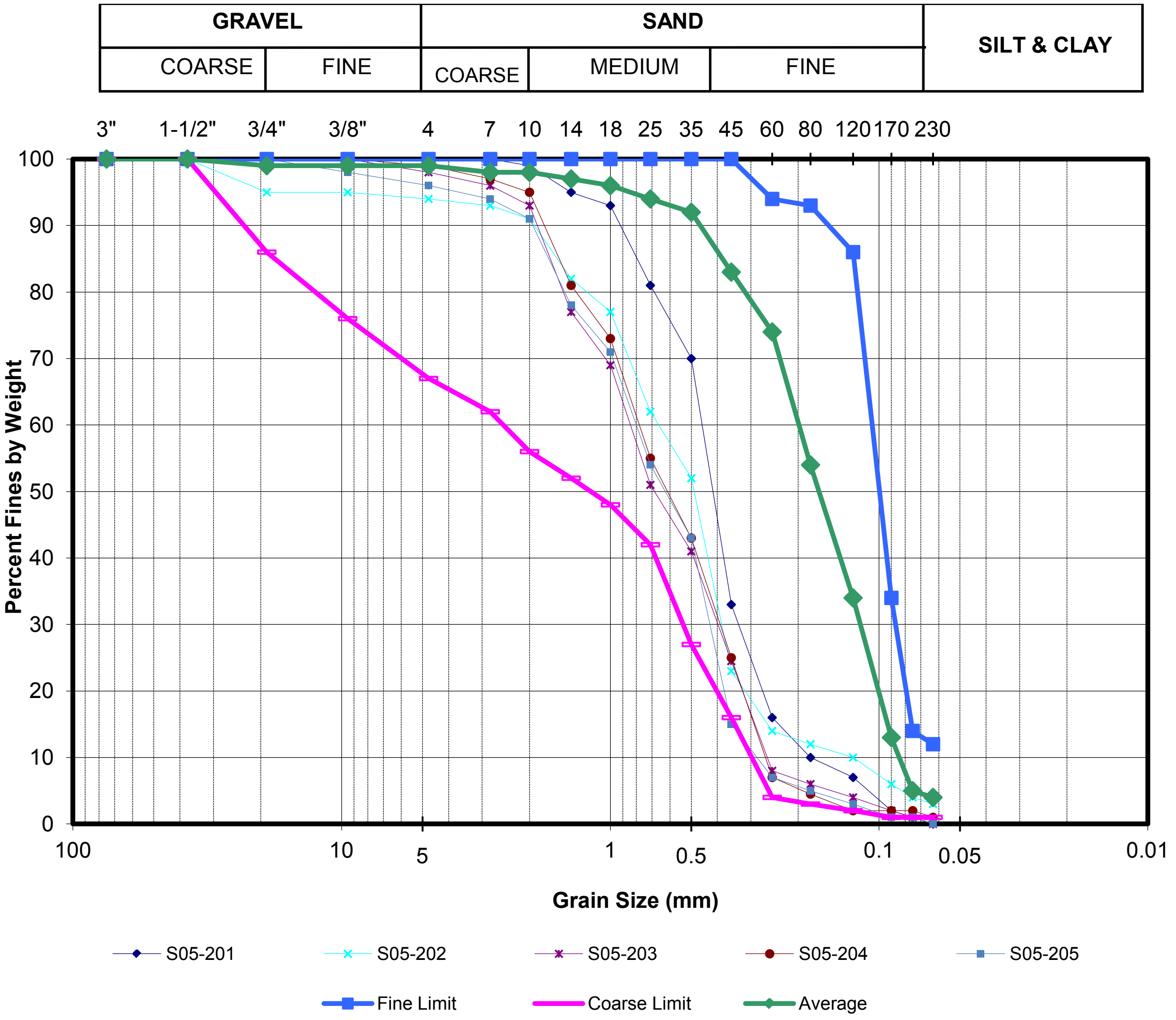
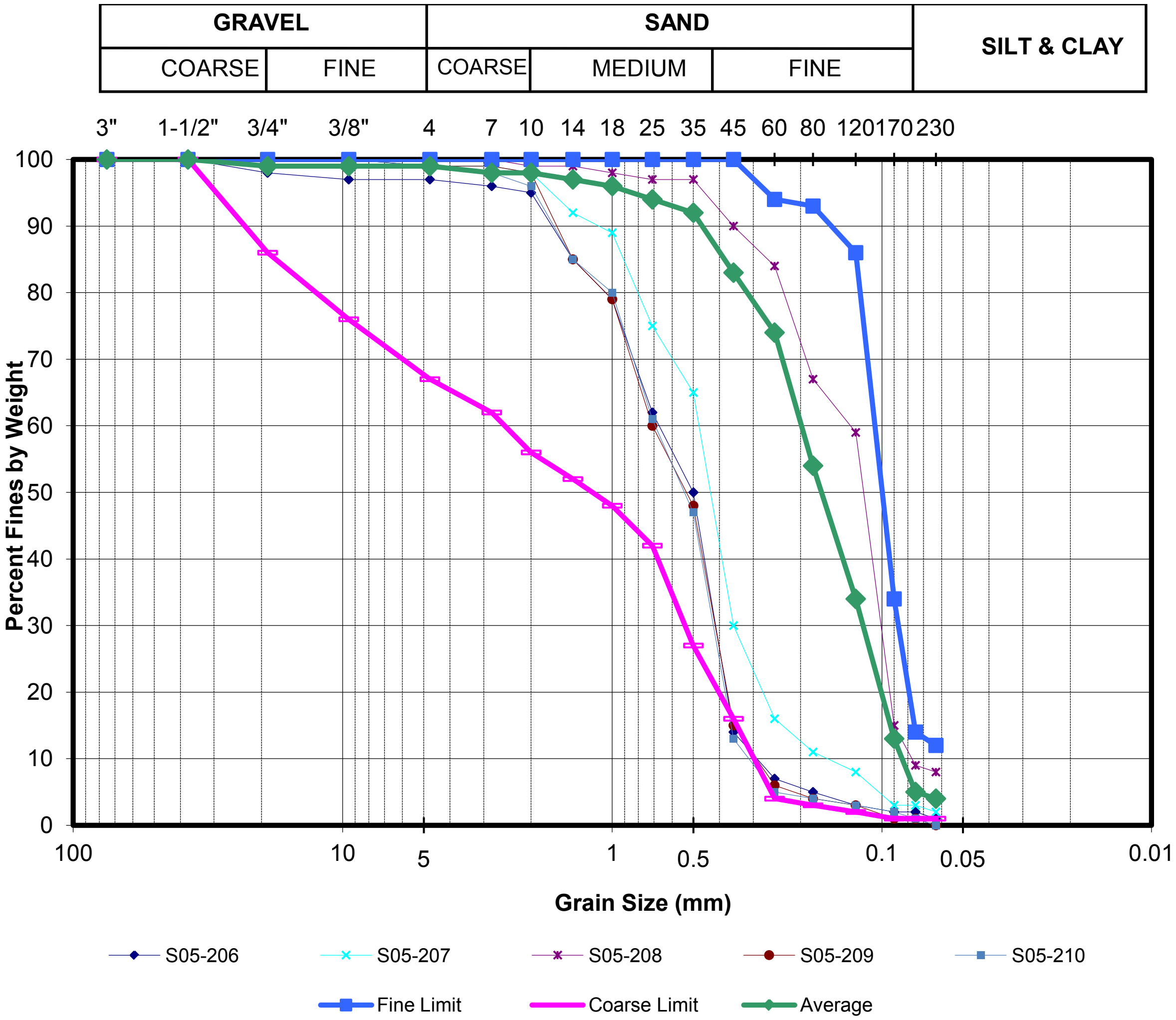
Part A Figures
Grain Size Compatibility Analysis Curves



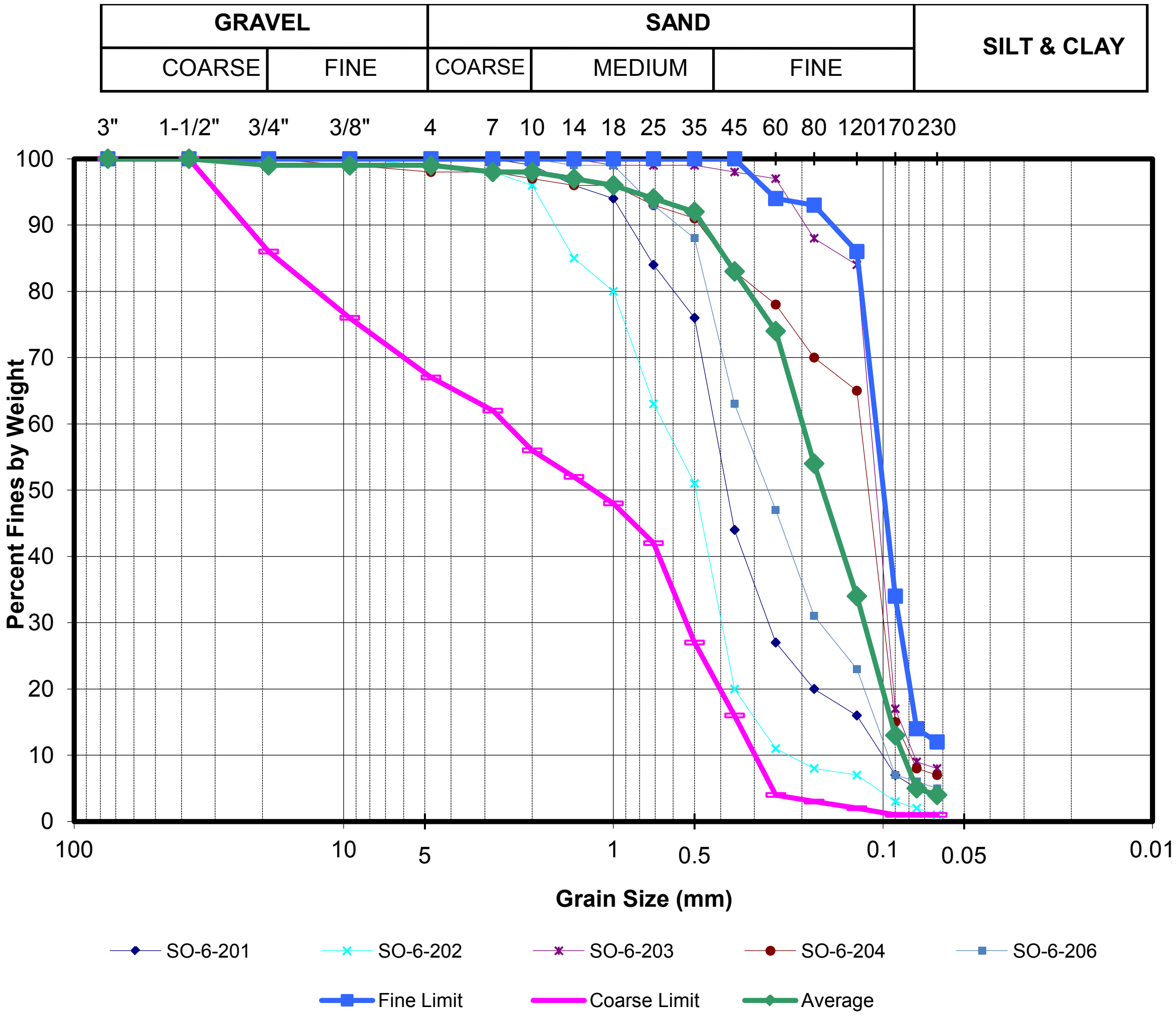
"RBSP II SO-5 offshore borrow site" (revised by USACE 2011)

Beach Compatibility Gradation Curves To 20 feet depth for RBSP II vibracores <u>SO-5-201 to 205</u>, using 2009 RBSP II beach profile transect data.



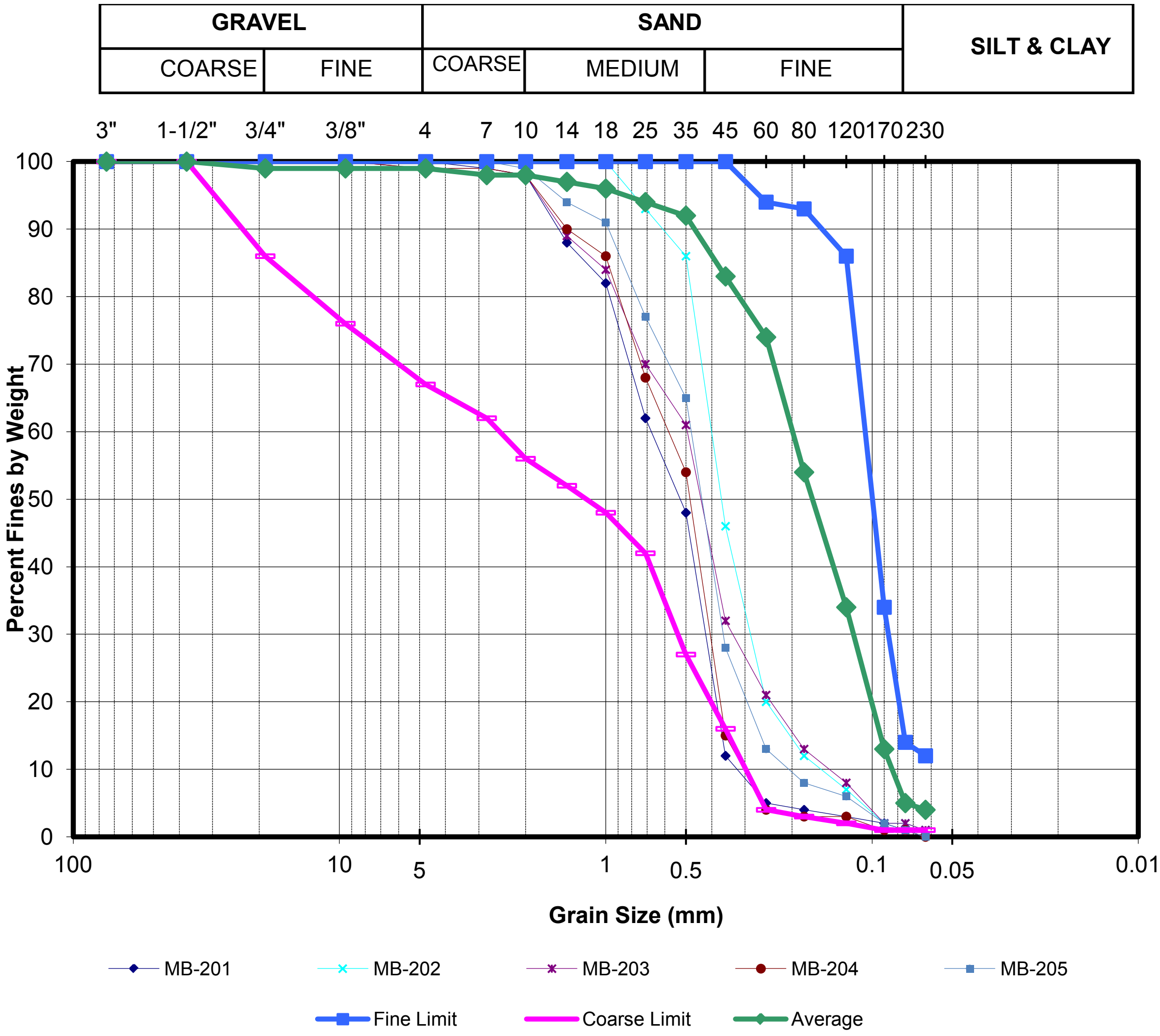
"RSBP II SO-5 offshore borrow site" (revised by USACE 2011)

Beach Compatibility Gradation Curves To 20 feet depth for RSBP II vibracores <u>SO-5-206 to 210</u>, using 2009 RBSP II beach profile transect data.

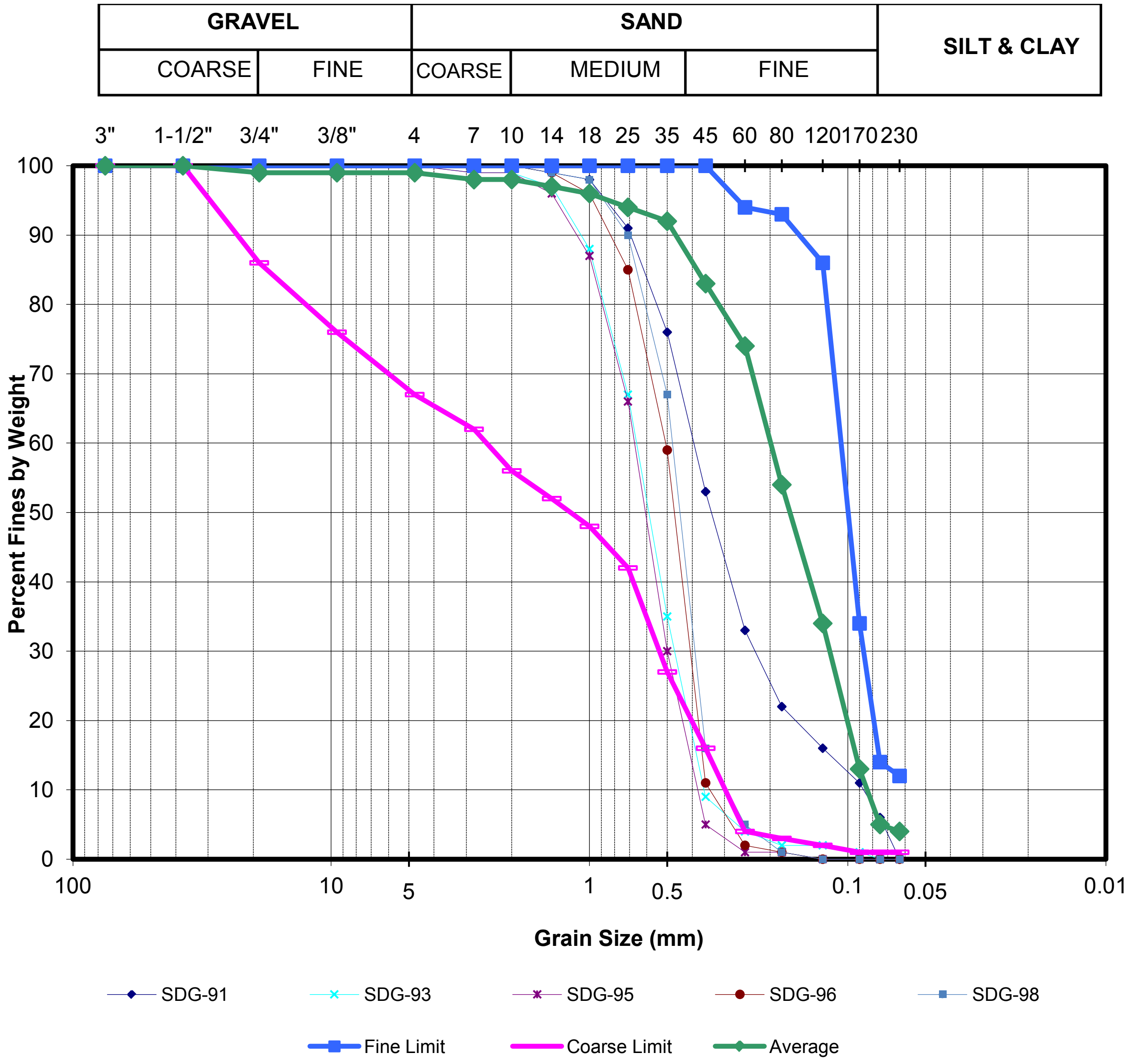


"RSBP II SO-6 offshore borrow site" (revised by USACE 2011)

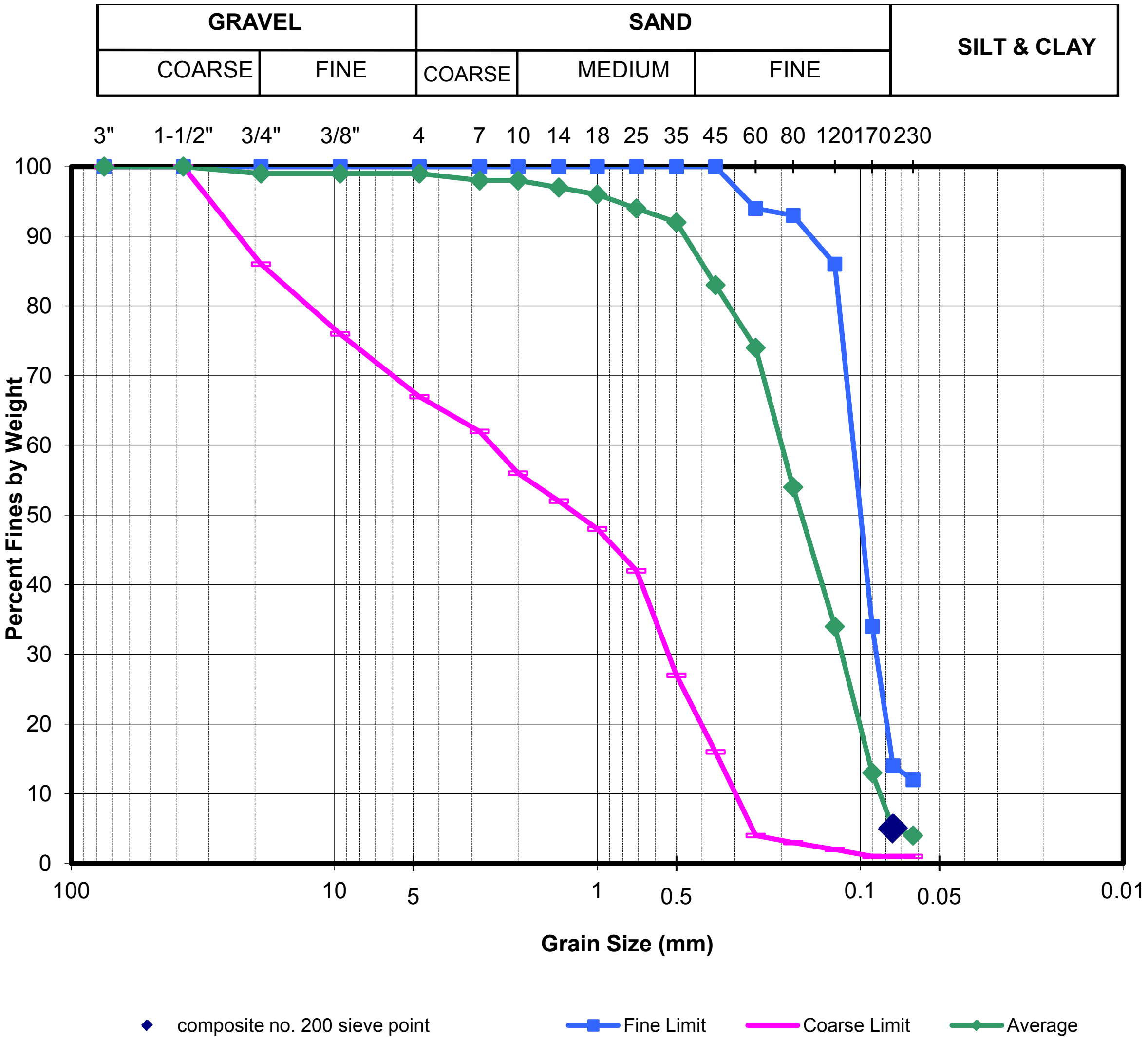
Beach Compatibility Gradation Curves To 20 feet Depth for RSBP II vibracores SO-6-201, 202, 203, 204 and 205, using 2009 RBSP beach profile transect data.



"RSBP II MB-1 offshore borrow area" (revised by USACE 2011)
Beach Compatibility Gradation Curves To 20 feet Depth for RSBP II vibracores MB-1-201 to 205, using 2009 RBSP beach profile transect data.

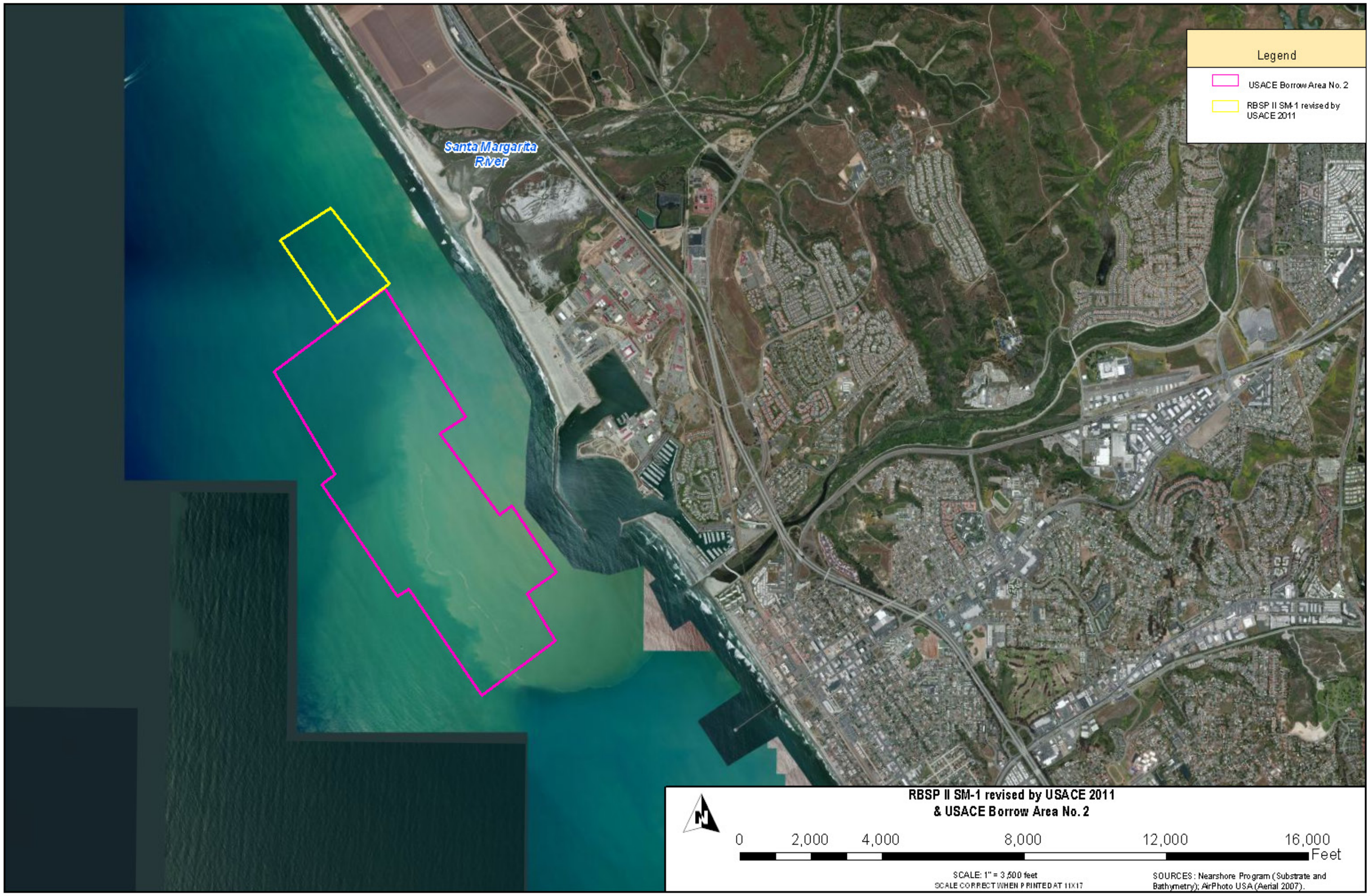


"RSBP II MB-1 offshore borrow area" (revised by USACE 2011)
Beach Compatibility Gradation Curves To 20 feet Depth for RSBP I vibracores <u>SDG-91, 93, 95, 96 and 98</u>, using 2009 RBSP beach profile transect data.



"USACE no.2 and RSBP II SM-1 offshore borrow areas" (revised by USACE 2011)
Beach Compatibility points based on no. 200 sieve to 20 feet Depth for RSBP I&II and USACE vibracores, using 2009 RBSP beach profile transect data.

Part B Figures
Selected Borrow Sites and Beach Profile Locations



RBSP II SM-1 revised by USACE 2011 & USACE Borrow Area No. 2

SCALE: 1" = 3,500 feet
SCALE CORRECT WHEN PRINTED AT 11X17

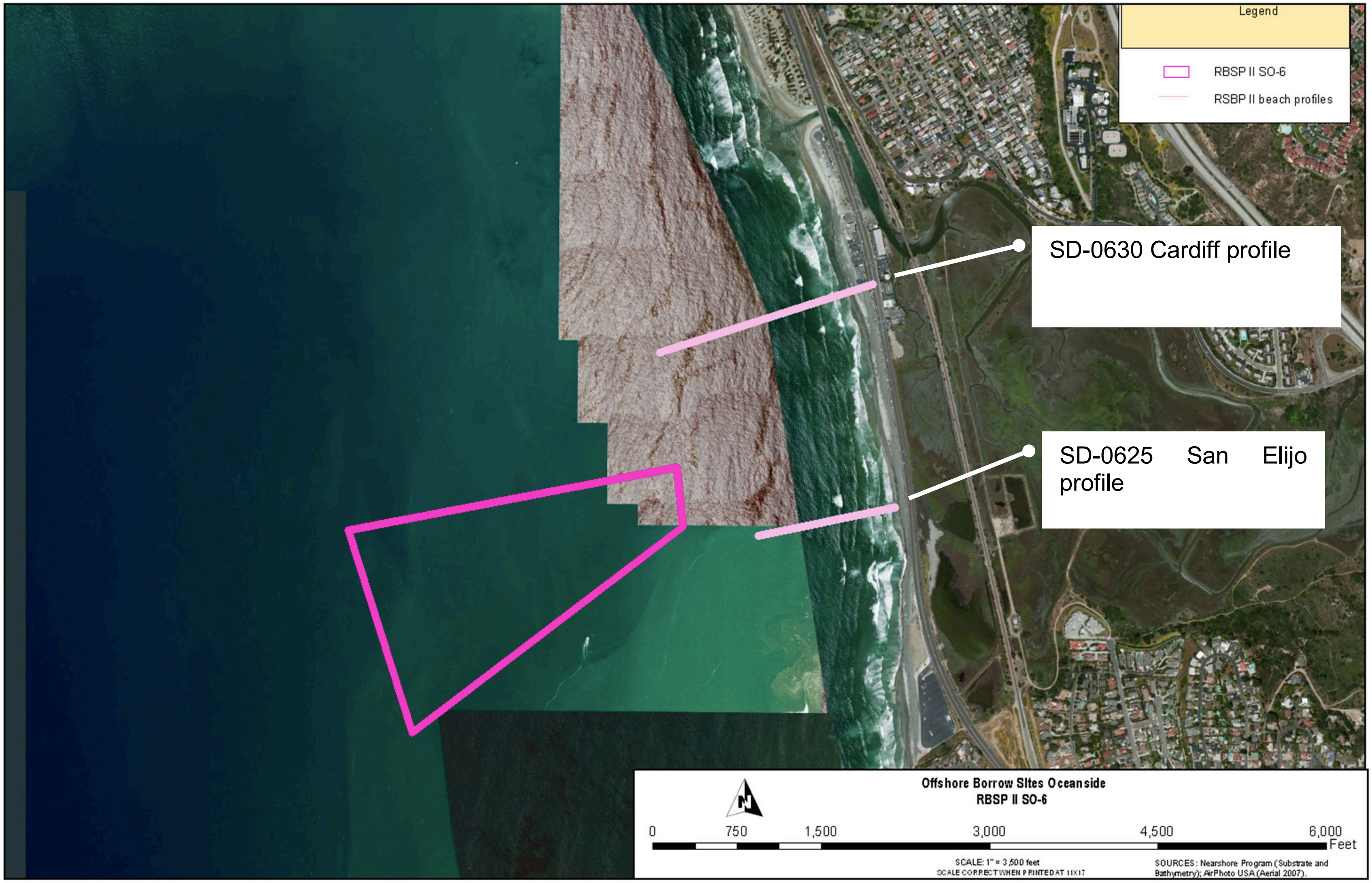
SOURCES: Nearshore Program (Substrate and Bathymetry); AirPhoto USA (Aerial 2007).

Offshore Borrow Areas Oceanside
SANDAG SM-1 and USACE Borrow Site no. 2

SANDAG RBSP II beach transect locations

SCALE: 1" = 3,500 feet
SCALE CORRECT WHEN PRINTED AT 11X17

SOURCES: Nearshore Program (Substrate and Bathymetry); AirPhoto USA (Aerial 2007).



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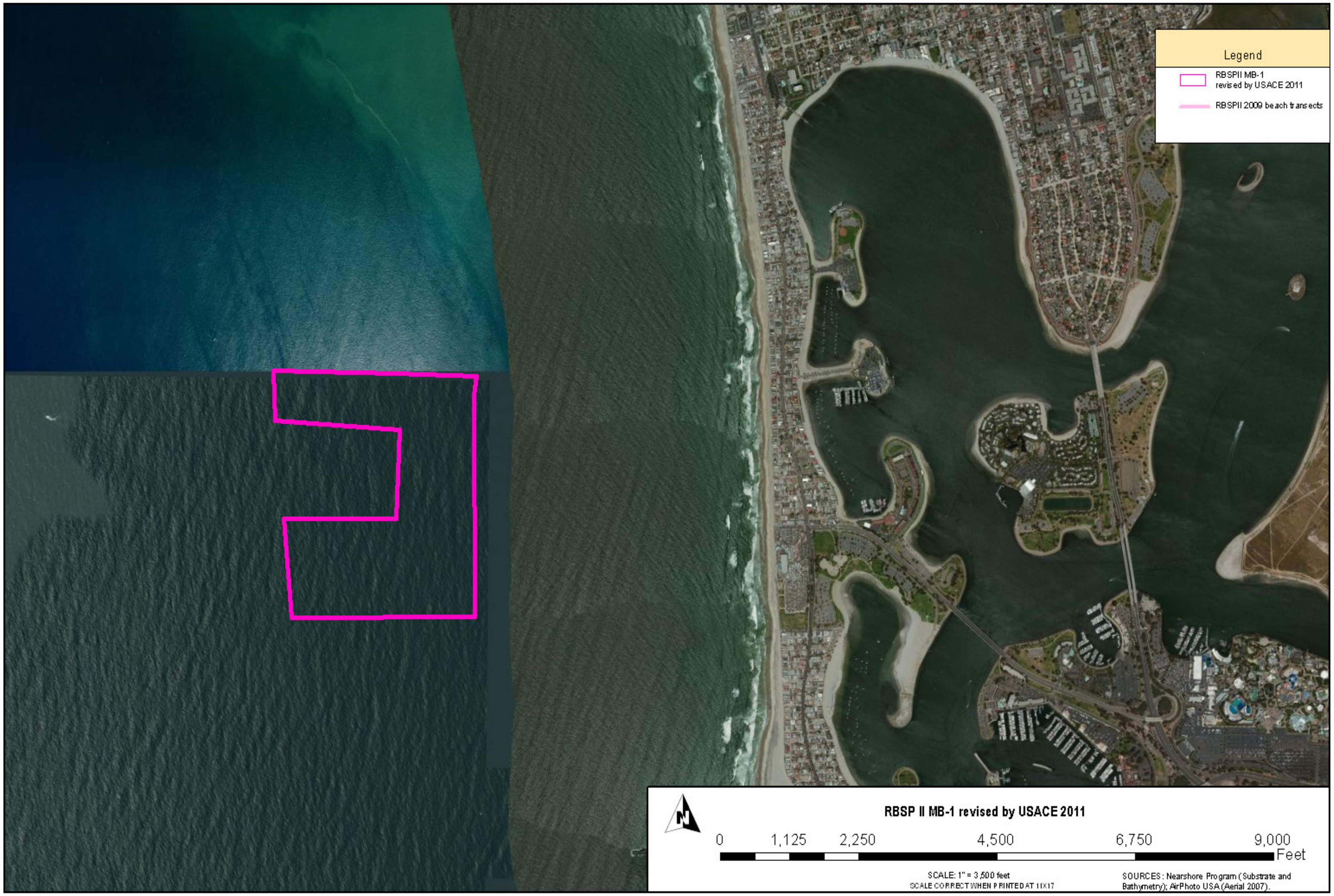
SOURCES: Nearshore Program (Substrate and Bathymetry); AirPhoto USA (Aerial 2007).



SOURCES: Nearshore Program (Substrate and Bathymetry); AirPhoto USA (Aerial 2007).