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Additional Keywords

Bay entrance, beach nourishment, beach profile surveys. beach width, harbor seiching, jetties, littoral sediment cell, Long Beach Port, Los Angeles Port, lowland restoration, piers, ports, sediment trapping, storm wave damage, subsidence mitigation, tidal entrances, tsunamis, wave climate

Abstract

The flood plain formed by detritus deposited by the Los Angeles, San Gabriel, and Santa Ana Rivers, and several streams is a multi-river delta at the coast and shelf of San Pedro Bay, a hook-shaped bight in southern California. It is between Point Fermin (southeastern tip of Palos Verdes Hills) on the northwest and Newport Bay/ Corona del Mar bluffs at the southeast. The 30-mile long shore has been extensively modified by anthropogenic activities and by natural events which are described; construction of dams for flood control (which also traps sediments), river mouth structures, ground subsidence owing to oil, gas and water withdrawal, structures and dredging at the entrances of landlocked bays (Alamitos, Anaheim, Newport), development and operation of marinas and navigation channels, encroachment by buildings and infrastructure. Sand beaches are along almost the entire shore: Long Beach Municipal Beach, Belmont Shore Beach, Seal Beach, Surfside Beach, Sunset County Beach, Bolsa Chica State Beach, Huntington Cliffs, Huntington City Beach, Huntington State Beach, Santa Ana River Mouth County Beach, West Newport Beach, Balboa Beach. The sand is light in color, and is mostly silicate (quartz and some feldspar). The beaches and surf, which are easily accessible, are popular and extensively used by residents and visitors. The natural supply of sediment to the coast became severely restricted, and beach erosion studies have been made since the 1930's; these are documented. There have been extensive beach nourishment (replenishment) projects for many decades which have successfully mitigated negative effects of sediment trapping, coastal structures, and ground subsidence. Dates, quantities and sources of the sediment placed as nourishment are given. Beach profile surveys and "Clancy beach width" measurements made during many decades were used to evaluate the effectiveness of the Surfside-Sunset beach project (including West Newport Beach). The wave climate in the Southern California Bight is complex. Six different meteorological patterns are the sources of the waves; they include North Pacific storms, local seas, and *southern swell* that have traveled thousands of miles from storms in the south 40 to 50 deg. latitudes. The waves are affected (refraction, diffraction, reflection, shoaling) by the islands, banks, submarine canyons, and local bathymetry of the California Continental Borderland. Sources of wave measurements, analysis, storage, and retrieval are given. The region is subject to storm waves, floods, droughts, seawater intrusion, earthquakes, tsunamis; some details of which are given. Damages caused by several severe wave events are described. A coastal lowland/wetland that was substantially impacted in the past century was

restored recently, the Bolsa Chica Lowlands Restoration Project. Its history and restoration (a modification of the original) is described. The largest seaport complex in the USA, by volume, is in the northwest part of San Pedro Bay, the contiguous Los Angeles and Long Beach Ports/Harbors; with 9.2 miles of breakwaters (in 3 sections, with 2 navigation entrances). The region has become extensively urbanized; it is part of the Los Angeles (Coastal) Megacity.

Introduction

The author has been familiar for many years with the low coastal alluvial flood plain delta of the Los Angeles, San Gabriel, and Santa Ana Rivers (and some streams) that presently discharge into San Pedro Bay, in southern California. Either the *Los Angeles, San Gabriel and Santa Ana Rivers Delta* or the *San Pedro Bay Delta* would be an appropriate name. It is extensively urbanized, and of major importance. Historical knowledge of it is short; only a few centuries. San Pedro Bay was named for St. Peter, a 4th Century A.D. bishop in Alexandria, Egypt (Wikipedia, 2008). It was "discovered" by Juan Rodriguez Cabrillo on 24 Nov. 1542. Richard Henry Dana, aboard the brig *Pilgrim*, and later the *Alert*, anchored in the open roadstead a number of times in 1835-1836. The region has been developed from one of little settlement and use, to extensive agricultural use, oil field exploitation (on land and offshore), industry, a vacation destination; and a large urban community, with associated commercial uses, living accommodations, recreational activities, and related infrastructure. It is within a coastal megacity; *Los Angeles Megacity* (Ewing, 2008). The population keeps increasing, but the length of ocean shore does not; however, the beach width can be, and has been, increased through the use of beach nourishment. This is a short history of the delta's shore and coastal facilities during the past 1-1/2 centuries, from a coastal engineering perspective.

The largest seaport complex in the USA, by volume, is located in San Pedro Bay - the contiguous Los Angeles and Long Beach Ports (e.g. Casey, 2009). These harbors/ports are sheltered by a series of 3 breakwaters built in 3 stages over many decades. They have a total length of 9.2 miles, including two ship channel entrance gaps. Navigation depths have been developed and maintained by dredging; channels, turning basins, berths. Southeast of the breakwaters there are 3 relatively small landlocked bays/ estuaries: Alamitos, Anaheim, and Newport. Each has jetties at its entrance (tidal inlet), dredged channels, and marinas. For flood control, the Los Angeles, San Gabriel, and Santa Ana Rivers have had channels with levees built near their mouths, and stone jetties constructed at their ocean outlets.

During the past century, the entire 30-mile long shore of San Pedro Bay has been modified by human activity, and by natural events. One example is ground subsidence that occurred owing to the withdrawal of oil and gas from underground reservoirs, onshore and offshore (e.g. the Wilmington, Huntington Beach, Huntington Beach New Offshore Oil Fields); and ground water extraction (artesian and pumped wells). Much of the coast/shore subsided; in several important ways the "equivalent" of a rise in relative mean sea level. As a result of water injection through wells into the underground areas, stabilization has occurred in some regions, and in some areas there has been partial rebound.

The flood plain/delta was formed by detritus deposited by the Los Angeles River, San Gabriel River, Santa Ana River, and several streams. The river courses have changed naturally over time, and as a result of actions by humans. Dams, debris retention structures (in small, steep canyons), levees, and other river control structures have been built; sediment (sand, gravel, silt, clay) has been trapped in reservoirs and debris retention structures, and sand and gravel mined from river beds. This has resulted in a substantial decrease in the natural supply of sediment to the coast. Floods, droughts, earthquakes, and seawater intrusion into the ground water aquifers, have occurred. Ocean waves have modified the beaches, and large wave events have caused beach erosion and destroyed or damaged buildings and infrastructure. Coastal structures (harbor entrances, river mouth jetties) have been built. Construction and maintenance dredging has been performed in bay entrances, navigation channels, turning basins, marinas, and river channels. The beaches are extensively used, and many have been nourished for decades by the addition of sediment obtained from dredging navigation projects, from "offshore borrow pits/ areas," or from adjacent river beds. At two beaches, sand has been "backpassed" from a section of accretion to a section of erosion/ recession. A coastal lowland/ wetland that was severely degraded by oil field activities during many decades in the past century (the 20th Century), including ground subsidence, has been re-established recently; the *Bolsa Chica Lowlands Restoration Project*. This project received the first Project Excellence Award, in 2008, of ASCE's COPRI (ASCE, Coasts, Oceans, Ports, and Rivers Institute, 2009).

The entire *San Pedro Littoral Sediment Cell* is along the delta; it extends from Point Fermin (at the southeastern tip of Palos Verdes Hills) on the northwest to Newport Bay entrance at the southeast, near the head of the Newport Submarine Canyon. The canyon head is close to shore, near Newport Pier, and is the joint southeast boundary of the cell. There is a continuous sand beach (mostly silicate sand; quartz and some feldspar) between Long Beach and the Newport Bay entrance jetties at the Corona del Mar headland/ bluffs: Long Beach Municipal Beach, Belmont Shore Beach, Seal Beach, Surfside Beach, Sunset County Beach, Bolsa Chica State Beach, Huntington Cliffs, Huntington City Beach, Huntington State Beach, Santa Ana River Mouth Beach (also known as Santa Ana River County Beach), West Newport Beach, Balboa Beach. The beaches and surf are well-used by residents and visitors (these are the nearest beaches to Disneyland). It is a world-known surfing center. They are popular for beach-going, swimming, body-surfing, surfboarding, windsurfing, fishing, and boating. The oceanfront is easily accessible.

[**Note**. Two terms are sometimes used interchangeably in coastal engineering publications, but they are different: beach erosion and recession. They are defined as follows in a report of the National Research Council's Committee on Beach Nourishment and Protection (1995, p. 44): "... *erosion* - a volumetric measure of the amount of sand removed from a beach by waves, currents, or other processes; *recession* - a linear measure of the landward movement of the shoreline." This is mentioned as in some references cited herein they have been used interchangeably.]

San Pedro Bay, In Southern California; Shore and Shore Use Changes During The Past 1-1/2 Centuries

San Pedro Bay, California, is a hook-shaped bight, oriented generally NW-SE, but with the "northerly" end bent sharply to the west toward Point Fermin and Palos Verdes Hills, Figures 1, 2 and 3. It faces southerly toward the San Pedro Channel. San Pedro Bay was discovered by Juan Rodriguez Cabrillo on 24 Nov. 1542, the feast day of St. Peter of Alexandria, a 4th Century A.D. bishop in Alexandria, Egypt. It was named *San Pedro* after "St. Peter" (Wikipedia, 2008). Los Angeles Port/Harbor and Long Beach Port/Harbor are contiguous; they are located at the westerly (and northerly) part of the bay. Alamitos Bay, Anaheim Bay, and Newport Bay, relatively small landlocked bays, are to the southeast; each with entrance jetties, navigation channels, and marinas. The head of Newport Submarine Canyon is close to shore, seaward of the Balboa Peninsula at Newport Bay, Figure 2. The predecessor to Newport Pier (McFaddens' Wharf) was built at this location because the waves were smaller locally, owing to their refraction by the canyon and contiguous bathymetry. To the south-southwest from Long Beach Harbor are Santa Catalina Island (about 25 miles), and San Clemente Island (about 60 miles). Santa Catalina Island is about 21-1/2 miles long, and San Clemente nearly 21 miles long. These and other nearby islands, and banks (e.g. Tanner Bank, Cortez Bank, 30-mile Bank, 40-mile Bank) of the *California Continental Borderland*, and submarine canyons have important substantial effects on the coastal wave climate in the *Southern California Bight*. The local nearshore and offshore bathymetry, such as the San Pedro shelf and the Newport Submarine Canyon, are important to the wave climate at the delta's coast (e.g., O'Brien, 1946; 1950; Horrer, 1950; Arthur, 1951; Jen, 1969; Pawka, 1983; Pawka, Inman and Guza, 1984; USACE, Los Angeles District, 1962; Dec. 2002; O'Reilly, 1993; O'Reilly and Guza, 1993; Adams, Inman and Graham, 2008).

The shore and shore use have changed dramatically during the past 1-1/2 centuries. Compare Figures 1, 2 and 3. See also photos of the coastal region (e.g., Patterson and Williamson, 1960; USACE, Los Angeles District, 1962, 1966/1967, 1986, Dec. 2002; Lee, 1973; Dorr, 1976/1985; Larkey, 1990; Google, 2009). A 7-page list of significant events for the coast of Orange County is in a USACE, Los Angeles District report (Dec. 2002). Compare historic photos with recent photos. An interesting example is an oblique Spence Air Photo of 1931, looking southeasterly over Anaheim Bay entrance (and Anaheim Landing) and Surfside Beach (in Dorr, p. 17), compared with recent aerial photos of the same area (e.g., Google). Copies of a few aerial photos are herein. As an example of the changes that have occurred, consider the following observation with what can be seen in recent aerial photos of Newport Bay/Balboa Peninsula (Beach), and what is described in several USACE, Los Angeles District reports. In September 1861, Assistant W.E. Greenwell of the U.S. Coast Survey, said of Newport Lagoon (U.S. Coast Survey, 1862, p. 66): "...The lagoon was found to be some five miles long, and separated from the ocean by a narrow strip of sand-beach, over which the heavy southeast and northwest swells wash in every great gale."

Tides are of the mixed regime, with "...two unequal daily high tides, and two unequal daily low tides" (e.g., Flick, Murray, and Ewing, 2003); there is a significant diurnal component (e.g., Zetler and Flick, July 1985). In Los Angeles (Outer Harbor), a Reference Station, MHHW is 5.5 ft., MHW is 4.8 ft., MLW is 0.9 ft., and HAT is 7.3 ft. relative to MLLW datum (NOAA/NOS, 2008). A table of predicted monthly and annual extreme high tides for 1983-2000 at Los Angeles (and for 3 other California ports) is in Zetler and Flick (March 1985, July 1985); based on the National Ocean Survey (NOS) 1960-1978 epoch (18.61 years). For effects on mean sea level along the California coast during episodes such as an El Nino phenomenon (ENSO), see Flick and Cayan (1985). Flick (1993, p. 6) said "...mean sea levels in southern California can be elevated by up to 15 cm above normal for several months to a year." During the "El Nino" (ENSO) winter of 1982-1983, a "record high water elevation of 7.96 feet (2.43 meters) above MLLW" was recorded at the Los Angeles Harbor tide gage (Walker, Nathan, Seymour, Strange III, 1985). The authors constructed a plot of water elevation above MLLW versus recurrence interval, using a Gumbel (Fisher-Tippett Type I) distribution. This elevation was a 130-year event based on prior events only, or a recurrence interval of 80 years including the event. (See also Cayan and Flick, 1985). For additional information on tides and sea-level change in this region, see "Trends in United States Tidal Datum Studies and Tide Range," by Flick, Murray, and Ewing (2003).

The diurnal inequality is such that the long runout follows the higher high water. O'Brien (1936) pointed out that "...The fact that the long runout follows higher high water is of importance in the improvement of tidal inlets since the tidal prism accumulates gradually during approximately three-quarters of the tidal cycle and is then discharged during a single ebb, giving the ebb currents a preponderant influence in scouring the entrance channel."

The climate is mild, temperatures moderate; dry summers and fall, and relatively wet winters which are variable. The beaches are extensively used by residents and visitors. They are easily accessible via the Pacific Coast Highway (PCH), which is just inshore of the beaches. Public parking is available between the highway and the beaches. An example of the numbers of beach-users is that given by King and Symes (2004) for the contiguous Huntington Beach City and State Beaches. They estimated the annual beach attendance to be in excess of ten million; probably circa 2000-2002, as they made a survey in 2002 of beach-users use of, and opinions about, beaches. Another example is an estimate by Prior (in Pratte, 1991) for Bolsa Chica State Beach; 2.75 million visitors in 1991. Surfing is a popular sport, and this region is world-known for it. The beaches and surf are a valuable economic resource for California and important to its economy (King and Symes, 2004; King, 2008). The population of this region keeps expanding, but the ocean shore length is about constant. However, the beach width can be increased by nourishment if sufficient beach quality sand is available; which has been the case for this reach of shore.

Ocean piers extend from shore through the surf zone, and are popular; to access the ocean, to access boats, to walk along, fish from, and observe surf from, for restaurants and shops. There are 5 piers: Belmont Pier, Seal Beach Pier, Huntington Beach Pier, Newport Pier, and Balboa Pier. The original Seal Beach Pier was built in 1906, 1,865 ft. long and 6 ft. wide; rebuilt in 1916 (Dorr, 1976/1985, p. 4). The present pier has a prestressed concrete sheet pile groin, about 750 feet long on its west side, built in 1959 (Herron, 1986; USACE, LAD, 1962; Dec. 2002). The pier was damaged by storm waves in 1982-1983; repaired, and reopened in 1984 (Spano, 1988). The original Huntington Beach Pier, 1,000 ft. long, was built in 1904, and nearly destroyed by storms in 1912; the second pier was built in 1914, and lengthened in 1930; the end of the pier was badly damaged by hurricane waves in 1939, and rebuilt in 1940 (Anon, 1992). The present Huntington Beach Pier was built in 1992, after it had been severely damaged by storm waves in 1982-1982 (Spano, 1988), and again in January 1988 (Malnic, 1988; Armstrong and Flick, 1989; Anon, 1992); 1,926 ft. long. The present Newport Pier, 1,030 ft. long, was built in 1935; partially destroyed by hurricane waves in Sept. 1939, rebuilt in 1940; rehabilitated in 1998 (Noble Consultants, Inc., 1998). [**Note** - the original pier, McFaddens' Wharf, was constructed by the McFadden brothers in 1888 as a dock for ocean-going ships, with a railroad built on top in 1891 (e.g., Gray, 2002); it was 1,300 ft long and 60 feet wide. It was rehabilitated in 1922 (Lee, 1973, p. 47)]. The original Balboa Pier, 925 ft. long, was built in 1906; it was largely destroyed by hurricane waves in Sept. 1939, and repaired in 1940 (Lee, 1973, p. 111-112); the present pier, 1,200 ft. long, was rebuilt in 1960; and rehabilitated in 1998 (Noble Consultants, Inc., 1998).

Boating is popular in southern California, and marinas have been built, some quite large; others have been proposed but the projects not implemented. Some information on entrance structures and navigation channels are in subsequent sections. In recent years the restoration and or maintenance of wetlands/ lowlands have received increasing attention. For example, Bolsa Chica Lowland Restoration Project, Seal Beach Natural Wildlife Refuge, Sunset Aquatic Regional Park, Upper Newport Bay. An example of protection or restoration of ecosystems in bays are the reconnaissance surveys, mapping, planting, and monitoring of eelgrass meadows/beds in Alamitos Bay, Anaheim Bay (Huntington Harbour, Sunset Aquatic Regional Park, U.S. Naval Weapons Station, National Wildlife Refuge), and Newport Bay (Ware, 1993).

Los Angeles, San Gabriel, and Santa Ana Rivers Alluvial Flood Plain and Coast; a Delta

The sandy shores (and formerly sand dunes), sloughs, tidal marshlands, and wetlands along the coast between San Pedro and the entrance to Newport Bay are parts of a multi-river delta. Either the *Los Angeles, San Gabriel and Santa Ana Rivers Delta* or the *San Pedro Bay Delta* would be an appropriate name. The delta is complicated by the Bolsa Chica Mesa, Huntington Beach Mesa, Newport Mesa. and the Newport-Inglewood fault zone. The shore is not of a "delta" shape; but the contiguous sea-bottom shelf is. There is considerable discussion about how to classify alluvial deltas (e.g. Coleman and Wright, 1975; Coleman, 1982; Wells and Coleman, 1984; Nemec, 1990). The author is not sure how to classify this one. The undersea part of the delta is illustrated by two figures in Edwards and Evans (2002), both in color. One is a computer-generated perspective view of the offshore and onshore of San Pedro Bay, Palos Verdes Hills, and Santa Monica Bay section of coast. [This was generated from high-resolution offshore bathymetric data and onshore data by J. Gardner and P. Dartnell of the USGS.] The other is a map showing the bathymetry, sediment-filled ancient stream channels crossing the offshore shelf area, including the offshore San Gabriel Canyon and the Newport Canyon. Wilson (1971) commented on the convex shape of the shelf offshore compared with the concavity of the coastline, and the importance of this in regard to the response (seiching) of San Pedro Bay and shelf to tsunamis and other long period forcings; this will be mentioned subsequently in the sections about seiching and tsunamis. This map includes the location of faults (Palos Verdes Fault Zone), and sediment thickness data on the shelf.

[**Note**. In addition to the Newport Submarine Canyon, some charts label another feature on the shelf a canyon, and a feature on the shelf edge a valley; San Gabriel Canyon, San Pedro Valley. Gorsline and Grant (1972, p. 580) mention these re-entrants, and say that "...seismic profiling indicates they are more likely slump scars associated with fault trends cutting the dome structure that forms the bedrock structure for the shelf surface." Details of the San Pedro Valley, the Palos Verdes Slope, and the Palos Verdes Submarine Debris Avalanche (Slide) are clearly evident in a perspective multi-beam shaded-relief oblique view of the undersea area in a paper by Normark, McGann and Sliter (2004); it is a modification of the shaded relief map of the region in Bohannon and Gardner (2004). The section herein on *tsunamis* has additional information about these.

A map showing historic natural channel courses prior to artificial controls of the Los Angeles, San Gabriel, and Santa Ana Rivers is reproduced herein, Figure 4 (from Brownlie and Taylor, 1981, p. C218). Everts Coastal (1996, p. 16) concluded that for a while (how long?) after the floods of 1861-62, the Santa Ana River flowed to the ocean through Bolsa Gap (sometimes called Bolsa Chica Gap), along the west side of Huntington Mesa.

The present locations of the ocean mouths of the

Los Angeles (and Rio Hondo), San Gabriel, and Santa Ana Rivers were fixed by construction of levees and jetties: Los Angeles River in 1921, with additional work in 1928, 1943-1944, and 1949 (Kenyon, Jr., 1952); San Gabriel River in 1932-1935, and 1940-1941; and the Santa Ana River in 1920, and its jetties lengthened in 1935, with other work also done (Shaw, 1980; USACE, Los Angeles District, Dec. 2002). Their locations are shown in Figure 3.

George Davidson, of the U.S. Coast Survey, wrote the following about San Pedro Bay and the contiguous coastal wetlands and floodplain in 1892, as quoted by U.S. Senator Stephen M. White in a speech in the U.S. Senate (White, 1896, p. 42):

"The bay is the northwestern limit of a very extensive plateau of comparatively shoal water along the seaboard from Point Fermin to about Newport, and the whole country behind the shore is sandy and so low that in winter it is flooded for miles inland by the rains and the overflowing of the low banks of the numerous streams frequently changing their course. The detritus from these streams is moving seaward and principally to the westward over this plateau and helping to extend it, by the action of the inshore eddy current."

Sloughs and other wetland areas, and sand dunes, that existed in Wilmington, Long Beach, Belmont Shore, Alamitos Bay, Anaheim Bay, Bolsa Chica can be seen in aerial photos of the 1920's and earlier (e.g. Dorr, 1976/1985; USACE, Los Angeles District, 1986; Dec. 2002; Larkey, 1990). An example is a 1921 photo of Alamitos Bay, Figure 5.

As a follow-up to Davidson's observations, refer to USC&GS Chart 5102 of 1928, Figure 2. Note the bathymetry of the region from Pt. Fermin to Newport Submarine Canyon, and southeast thereof. There is an abrupt change in depth between about the 40 fathom and 100 fathom contours, which Emery (1960, p. 204) refers to as a shelf-break. Notice the shape of the shelf. The shelf was probably formed in large part by deposits of sediment from the Los Angeles, San Gabriel, and Santa Ana Rivers. Emery (1960, Fig. 180) identifies areas of the bottom sediments that are medium sand, fine sand, mud (a mixture of silt and clay) and relict coarse red sands; the red color is due to a thin stain of ferric oxide. Except for the relict sands, Emery (p. 203) says the sediments consist chiefly of quartz and feldspar, with some heavy minerals. He says: "...These detrital sediments consist mostly of sands and silts which form seaward continuations of the beaches," which are mostly of river origin.

As a result of their mineralogical and textural studies of the bottom sediments of the San Pedro Shelf, Gorsline and Grant (1972, p. 588) concluded in regard to the source of the "...dominant and probably contemporary sediment type"... that "...the Los Angeles, San Gabriel, and Santa Ana Rivers are probable contributors...together with a very minor contribution from the northern sources." They also concluded (p. 598) that the entire shelf "...is an active sedimentary province in which surficial sediments are being modified to depths of at least 100 m by wave and current action within a period of twenty years and quite probably much less."

Sediment thickness data on the shelf are shown by Edwards and Evans (2002) in a perspective view map of the shelf.

Oil fields are under the shelf. They have been, and some still are, exploited by use of slant drilling from shore in the Bolsa Chica and Huntington Cliffs area; and directional drilling from manmade islands offshore.

San Pedro Littoral Sediment Cell; River Ocean Outlets and Bay Entrances

The *San Pedro Littoral Sediment Cell*, about 30 miles in length, is between Point Fermin (the southeastern tip of Palos Verdes Hills) which is westerly of Long Beach, CA, and the Newport Bay entrance/ Corona del Mar bluffs to the southeast. The head of Newport Submarine Canyon just offshore the Balboa Peninsula (Beach), near Newport Pier, is the joint southeastern boundary of this littoral sediment cell. Most of the sediment cell is in Orange County, with the northwest portion in Los Angeles County. [**Note**. The Los Angeles County/ Orange County boundary runs along the centerline between the Alamitos Bay entrance jetties. Orange County was originally a part of Los Angeles County; the southern 40 miles became a separate county on 1 Aug. 1889 (Lee, 1973, p. 47).] Sub-cells are: Los Angeles/ Long Beach Harbors; Seal Beach (between Alamitos Bay and Anaheim Bay entrances); Huntington Beach (between Anaheim Bay entrance jetties and the Santa Ana River mouth jetties); West Newport Beach - Balboa Peninsula (between the Santa Ana River mouth and the Newport Bay entrance jetties at Corona del Mar Bluffs).

Construction of the San Pedro (1889-1910), Middle (1932-1942) and Long Beach Detached (1943-1949) breakwaters, a total length of 9.2 miles (including 2 navigation channel gaps), altered substantially the historic San Pedro Littoral Sediment Cell (e.g., USACE, Los Angeles District, 1966/1967; 1986; Dec. 2002; Flick, 1993).

Beach sand in this littoral sediment cell is mostly silicate (quartz and feldspar); light color, and of medium grain size. The median diameters range between 0.1 and 1 mm (USACE, Los Angeles District, March 1993, April 1993; Dec. 2002, p. 3-5). A plot of the median grain size of many samples taken along the beaches is in Fig. 3-20 of the Corps' Dec. 2002 report; samples were obtained at "elevations of +3.7 m, 0 m, and -3.7 m MLLW." An earlier Corps' report (U.S. Congress, 1940, paragraph 60) said sand samples were taken at 93 stations along Orange County beaches "...at about mid-tide elevation ...The medium diameter of the particles ... varied from 0.61 to 0.06 mm. ... The average median diameter for open beaches where dredged materials have not been deposited and where there are no protective structures is about 0.27 millimeters." The specific gravities varied from 2.70 to 2.53; the average of all samples was 2.63.

The original sand sources were fluvial; the Los Angeles, San Gabriel, and Santa Ana Rivers, and a few small streams; and some from sea cliff (bluff) erosion (e.g. USACE, Los Angeles District, 1962; Dec. 2002; Patsch and Griggs, 2005). Dams have been built on the rivers, and debris retention structures on steep tributaries and streams, which have trapped sand and other size sediments. These have reduced greatly the supply of sediment to the coast (e.g., U.S. Congress, 1940; Brownlie and Taylor, 1981; USACE, Los Angeles District, 1962, Dec. 2002; Flick, 1993; Magoon, Williams, et al., 2005). In recent years the principal source has been beach nourishment, although there is still some fluvial supply and some from sea cliff erosion. Sand transport alongshore is either "downcoast" (toward the SE) or "upcoast" (toward the NW) on the beaches between Long Beach and Newport Bay entrance, depending on the local wave direction. It is cyclic, generally to the southeast in the winter months, and often toward the northwest in the summer months (caused by *southern swell*). The net direction of alongshore transport is toward the southeast, except for the section (Seal Beach) northwest of Anaheim Bay entrance (since the construction of the Long Beach Detached Breakwater); and the section between the Santa Ana River mouth and about 46th St., West Newport Beach. The direction of net transport in these two reaches is from SE to NW. There is a change in shoreline orientation in the vicinity of 46th St. (e.g., U.S. Congress, 1940; USACE, LAD, 1993; Dec. 2002).

The sediment sink of the Huntington Beach Littoral Sediment Sub-cell is usually considered to be the Newport Submarine Canyon. However, observations by scientist-divers in and near the canyon indicate it had not been a sink during, or for several decades prior to, their investigations (Interstate Electronics Corp., 1966; Felix, 1969; Everts Coastal, 1996). Their studies, including diving, indicated to them that little sand was going into the canyon at or near the head, at least then. It is likely to be an episodic event. We do not seem to understand adequately sediment transport mechanisms at or near some submarine canyons, such as this one. The sediment sink is probably a combination of the undersea delta and the submarine canyon, with some sand transported out of the subcell along the base of the sea cliffs southeast of Corona del Mar bluffs.

Los Angeles River now discharges into Long Beach Outer Harbor through a flood control channel, with levees built in 1921-1923 (McQuat, 1951); and modified with additional works in 1929, 1943-1944, and 1949 (Kenyon, Jr., 1951). The levees extend due south through Long Beach to the ocean; they are about 4-1/2 miles long. In 1927 a stone breakwater was built into the ocean, an extension of the westerly bank of the river (U.S. Congress, 1940, paragraph 58). It was "...extended southerly 4,300 ft. into the ocean, and thence in a southwesterly direction towards San Pedro" (Kenyon, Jr., 1951). Surveys in 1935 and 1938 showed a large amount of sand and silt had been deposited offshore during that interval, about 2.2 million cu. yds.; much of it during the flood of March 1938. In 1943-1944, the west bank of the outlet "...was extended seaward 3,500 feet to the southeast in a long-radius curve from shore by construction of a dike faced with rock riprap" (Kenyon, Jr., 1951). The dike was extended 700 ft. in 1946, and an additional 975 ft. in 1949. Since then the river has discharged towards the southeast, past (now) the permanently moored Queen Mary. The location of the outlet system is mapped on Figure 3; more details can be seen on NOAA Chart 18751, *Los Angeles and Long Beach Harbor, California, United States, West Coast* (NOAA, 2007).

The U.S. Coast Survey map *California from Point Fermin Eastward to San Gabriel River, Surveyed 1859* (see McQuat, 1951) shows the San Gabriel River mouth located just east of Rattlesnake (later renamed Terminal) Island. During floods in 1868 the river cut a new channel, and flowed into Alamitos Bay. It flowed into this bay until 1933-1935, when a new flood channel outlet was constructed, with levees and stone jetties at its mouth (Kenyon, Jr., 1951). The channel was from a point a few thousand feet upstream, to the ocean just east of the bay entrance (Kenyon, Jr., 1951; U.S. Congress, 1954, p. 10). The "before" and "after" conditions can be seen in the 1921 and 1940 aerial photos, Figures 5 and 6. The "East" and "West" jetties for the new San Gabriel River mouth were completed in 1932 and 1933, respectively (e.g. Orange County Planning Commission, 1941, p. 20; U.S. Congress, 1962, p. 38). The eastern jetty was longer, 750 ft. "...A 700-foot gap was left in the west levee just inside the tip of the peninsula, in order to take advantage of the scouring action of the tidal prism for maintaining the flood-channel inlet." The then western (the present "central") jetty was extended from 375 ft. to 800 ft. in 1940-1941 "...to retard shoaling of the outlet by downcoast littoral drift" (U.S. Congress, 1962, p. 38). Owing to problems and requirements associated with river sedimentation, and the cooling water intake and discharge system for the condensers of the steam-electric power plant in Seal Beach, at the bay entrance/ river mouth, it was decided to have a separate entrance to the bay (Kenyon, 1951). The present "west" ("upcoast") jetty of the bay entrance was built 600 ft. "west" of the river mouth in 1944; it was 800 feet long. The new bay entrance was dredged in 1945-1946, and the 800,000 cu. yds. of material dredged were placed along the beach "...upcoast from the west jetty of the bay entrance" (Kenyon, Jr., 1951). Alamitos Bay was then separated from the San Gabriel River ocean outlet. The bay entrance and seaward bars were dredged in 1950 (U.S. Congress 1954, p. 11); the sediment was placed along the peninsula segment of shore. Thus, there are three stone jetties at the contiguous bay entrance/ river mouth outlet. Long Beach Marina was constructed in 1954, and 800,000 cu. yds. of sediment placed on the Seal Beach shore (U.S. Congress, 1962, p. 38). The two jetties at the bay entrance were extended to a length of 3,000 ft. (Nathan, 1994); these are the "west" and "center" jetties. Plate 1 of U.S. Congress (1962) shows both jetties at the entrance to Alamitos Bay to be 3,000 ft. long; see 1964 aerial photo, Figure 7. [Note. The author has not been able to find a reference to the date they were extended.]

In 1867, *Anaheim Landing* was established just inside the entrance to Anaheim Bay, on the west side; a very small port (Dorr, 1978/1985, p. 6). It is shown on the U.S. Coast Survey Map *Topography, New River to Bolsas*

Creek, Surveyed 1873, and on a U.S. Coast & Geodetic Survey Map surveyed in 1894. It was there until World War II; when, in 1944 the U.S Navy Ammunition and Net Depot (NAND) was established in Anaheim Bay. In 1962 this depot became the U.S. Naval Weapons Station Seal Beach (Dorr, 1978/1985, p. 40). Two stone "arrowhead jetties" (also referred to as breakwaters) were constructed at the Anaheim Bay entrance in 1944. The west jetty is 914 ft. long, and the east jetty 1,150 ft, long). The entrance was dredged, and maintenance dredging has been done on a number of occasions. In this small landlocked bay are: U.S. Naval Weapons Station Seal Beach, Seal Beach National Wildlife Refuge, Sunset Aquatic Regional Park, and Huntington Harbour (a residential marina).

For about a century, Bolsa Chica Bay was connected to Anaheim Bay via Outer Bolsa Bay by a manmade narrow channel (canal) that was dug in 1899 from the outer bay; with a tide gate at the easterly end of the outer bay. The new *Bolsa Chica Lowlands Restoration Project*, completed in 2006, includes a non-navigable ocean entrance which was constructed through the beach, rather than being connected to Anaheim Bay and its ocean entrance via the canal and Huntington Harbour. The project is described in a another section herein, but it should be mentioned here that the East Garden Grove/ Wintersburg flood control channel does not discharge into the new lowland restoration project. Rather, it remains connected, with a tide gate, to Outer Bolsa Bay, thence through the canal, Huntington Harbour, Anaheim Bay and its ocean entrance.

The Santa Ana River mouth stone jetties were built 5.1 miles northwest of the Newport Bay entrance in 1920 (Patterson and Williamson, 1960). They are 500 feet apart. Bitter Point Dam was built between the new river mouth and Newport Bay as part of this project, to prevent the river from flowing into the bay (see sketch in Lee, 1973, p. 82). The jetties were extended, and major additional construction done in 1935. The outlet was dredged in 1969-1970 (Shaw, 1980), and the river bed in 1992 (USACE, Los Angeles District, Dec. 2002).

In addition to the river mouth jetties, there is a flood control structure near the Santa Ana River mouth, with an ocean outlet; the Talbert Channel. It has two jetties that cross the beach, and is located about 1,000 feet northwest of the Santa Ana River mouth. The previous Talbert Channel jetties were immediately adjacent to the river mouth's northwesterly jetty. The jetties are relatively short, each 162 m in length; the channel width is 40 m. The present outlet was opened in April 1991 (Leidersdorf, Smith, and Li, 1992). It is part of the Orange County Flood Control District, for a local drainage area. Aerial photos (June 1986 and June 1991) of the present and the earlier outlets are in the paper.

Jetties were built at the Newport Bay entrance (1917, 1921, 1927); both jetties were extended in 1934 - 1936, and the entrance dredged (U.S. Congress, Senate Committee on Commerce, 1937; Patterson and Williamson, 1960). The jetties were damaged by hurricane waves on 20 Sept. 1939, and repaired in 1940 (Lee, 1973, pp 103, 112). The entrance was dredged in 1960 (Shaw, 1980). A popular surfing break exists at the west jetty and beach, known as *The Wedge*; it is described in another section.

Now, back to rivers; with their floods and changes in courses. Refer to Figure 4.

In 1825, during a great flood, the Los Angeles River overflowed its banks, and changed its course from flowing southwesterly into Santa Monica Bay through Ballona Creek (near the present Los Angeles International Airport), to flow south into Wilmington Lagoon and San Pedro Bay (e.g., Troxell and Others, 1942; Kenyon, Jr., 1951; Gumprecht, 1999). The San Gabriel River, and its western branch, the Rio Hondo, joined the Los Angeles River in flowing into Wilmington Lagoon and San Pedro Bay. During major floods it switched back and forth. In the flood of 1867-1868 the San Gabriel River broke out of its channel and formed New River, flowing into Alamitos Bay (e.g. Troxell and Others, 1942, pp 339, 391; Kenyon, Jr., 1951). It is shown as New River Slough on the U.S. Coast Survey Map: *Topography, New River to Bolsas Creek, Cal. 1873*, Register No. 1345. It is also shown on the 1886 U.S. Coast Survey Chart 5143 of San Pedro Bay. During the winter of 1910-1911, the San Gabriel River broke its regular channel, and flowed into New River, united with Los Angeles River, and flowed into the sea; one of the worst floods in many years (Fries, 1912, pp 29-30). The Santa Ana River has flowed into the sea at several locations between Alamitos Bay and Newport Bay, or through Newport Bay (estuary/lagoon).

A map-like sketch in the paper by Patterson and Williamson (1960) shows the location of the Santa Ana River mouth from 1825 to the late 1870's. They wrote: "The Santa Ana River emptied into Anaheim Bay for a period prior to 1825. In that year unusually heavy floods caused the river to adopt a new channel immediately southeast of Huntington Beach Mesa...An 1825 chart of Newport Bay shows the sand spit's easterly tip at a point approximately 8,000 feet northwest of the present harbor entrance. In the great flood of 1861, the river mouth was shifted nearly to the Corona del Mar bluffs... A short sand spit grew out from the Corona del Mar rocks, and for a number of years the mouth of this newly created bay hovered about a locality one-third of a mile west of the present entrance." At the time of the U.S. Coast Survey's survey in 1878 the river flowed into the bay, and the river mouth/ bay entrance was at the base of the Corona del Mar bluffs; Figure 14.

Troxell and Others (1942, p. 339) say:
"It is known, for example, that within historical time, the Los Angeles River has reached the ocean through Ballona Creek. During the same period the San Gabriel River has shifted several times between its present channel, the bed of the Rio Hondo, and the former course of the Los Angeles River. The Santa Ana River, also, has occupied several channels within an area extending from Anaheim Creek to Newport Bay. Thus, the lower part of the coastal basin is in reality a flood plain fed by the flows of these three rivers." [**Note.** A century ago, artesian wells were common in the coastal region of Orange County.]

A feeling for the historic flooding of this coastal alluvial floodplain can be obtained by looking at the aerial photos of the Santa Ana River overflow in the vicinity of its mouth and the Winterberg to Westminister area taken during the flood of 1938 and by reading descriptions of the event (Troxell and Others, 1942). The storm centered in the San Gabriel and San Bernardino Mountain areas, with rainfall measurements indicating from 20 to 30 inches of rain during 27 February- 4 March 1938.

Thomas Talbert was a young farmer and store keeper in the Huntington Beach region in the 1890's; subsequently in real estate, and in the 1930's, councilman and mayor of Huntington Beach. He wrote (1952, p. 57): "In the time of heavy floods the Santa Ana River has frequently joined the Freeman River (sic, Creek) to empty into the ocean at Los Patos, Bolsa Chica. It has even been known to swing far enough to the west to join the San Gabriel River and flow out through Alamitos Bay. When this occurred, it was possible to go by boat from the Costa Mesa Bluffs to the Fred Bixby ranch in Long Beach."

Talbert (1952, p. 63) described his observation of river flooding through a bay, while a flood tide was running, and what occurred when the tide started to ebb. He said that what took place at Bolsa Chica Bay and at Los Patos, and Alamitos Bay were similar, but at smaller scale, to the occurrence at the Santa Ana River/ Newport Bay entrance, where a "tremendous current" washed out the sediment deposits and kept the ocean entrance channel open.

Los Angeles and Long Beach Ports/Harbors

This section is mostly about the early technical history of the Ports/ Harbors of Los Angeles and Long Beach, rather than details of the present day extensive and diversified facilities which are intermodal (ship, truck, train); or of the political history. This would require a separate report. At the end of this section however, as an example of modern development, a brief description is given of the construction of the extensive Pier 400. The two seaports and harbors are contiguous, Figure 3; they are harbors of both refuge and commerce. The combined port complex is the largest in the USA by volume (e.g. Casey, 2009). The arrangements of the Ports/ Harbors of Los Angeles and Long Beach are shown in NOAA chart *Los Angeles and Long Beach Harbor, California*, Chart No. 18751, 45th Ed., Nov. 2007 (corrected through Nov. 03, 2007), scale 1:12,000. The Port of Los Angeles is connected to the downtown and industrial parts of the City of Los Angeles by a strip of land along Alameda Street, which was annexed by the City of Los Angeles in 1906. The towns of Wilmington first, and then San Pedro, were annexed by the City of Los Angeles in 1909 (McQuat, 1951).

[**Note.** Substantial ground subsidence occurred in this area. Owing to its magnitude and importance in the Port of Los Angeles and Port of Long Beach region, a separate section about *subsidence* is in this report.]

The predecessor to these seaports was the open roadstead in the western area of San Pedro Bay, partially sheltered by Pt. Fermin; and within Wilmington Bay (Lagoon).[**Note.** Richard Henry Dana, in his book *Two Years Before The Mast*, described anchoring the brig *Pilgrim*, and later a larger ship, the *Alert*, in the open roadstead on a number of occasions in 1835-1836; and loading aboard hides. Dana said (1927, p. 113) it had a reputation as a poor harbor owing to its exposure to southeasterly winds and seas. And, it was so shallow that "...the sea broke often as far out as where we lay at anchor;"... also "... seas actually broke over the Dead Man's Island"...and a small launch "...snapped her cable and drove up over the breakers, high and dry upon the beach."]

The entrance to Wilmington Bay was (and is) at the southwest end of 4-mile long Terminal Island (formerly known as Rattlesnake Island). Wilmington Bay and Cerritos Slough were between Terminal Island and the mainland; and at that time the Los Angeles River flowed into the ocean just northeast of Terminal Island. These are shown on a 1859 U.S. Geological Survey Chart. Improvements to the entrance for boats and lighters by the U.S. Government began in 1871 (Fries, 1912). Jetties were built "to straighten and deepen the entrance to the inner harbor."...The east jetty, built in 1871-1881 at the entrance, was in three sections, a total of 6,700 feet in length; it extended to Deadman's Island. [Deadman's Island was removed in 1928 (McQuat, 1951).] The much shorter west jetty was on the landward side in the vicinity of Timms Point. The San Pedro Breakwater was built in 1889-1910, 11,000 feet long. It has a random stone core and "fitted stone masonry" armor on both sides (e.g., Lillevang, 1986). [**Note.** Details of the location of the harbor, arrangement of facilities, navigation channels, basins, harbor lines, design and construction of the jetties and breakwater, and several photos are in Fries (1912). Details of the design and construction of the breakwaters, and the political history of the harbor, are in McQuat (1951).] Originally there was a gap of 1,900 feet between shore and the breakwater. In 1908 it was decided to close this gap, and the work was completed in 1912. The open roadstead which was in the lee of Point Fermin, then was between the breakwater and shore; this created what was known as a harbor of refuge. At a later date, the Cerritos Channel was constructed through Cerritos Slough to connect the inner harbors of Los Angeles and Long Beach.

Development of Long Beach Harbor began in 1906 (McQuat, 1951). In 1916 the City of Long Beach received a deed to the channels, turning basins, and some acreage of the Inner Harbor. As mentioned in a previous section, a new channel was built during 1921-1923 for the Los Angeles River; a flood control project that ran due south through the city to the ocean (McQuat, 1951). The river and its sediment load were a major problem. In 1924 development of the Outer Harbor began. Details of the breakwater construction are in McQuat (1951). Several aerial photos taken in the 1920's and a map of the port/harbor are in Larkey (1990). Kenyon, Jr. (1951) wrote that a large amount of sediment accumulated in the Los Angeles River channel, and a delta formed seaward of its mouth. A stone breakwater was built on the westerly bank of the river channel in 1927-1929. This breakwater, the Long Beach (Harbor) Breakwater (sometimes called the Original Long Beach Breakwater)

"...extended southerly 4,300 ft. into the ocean and thence in a southwesterly direction towards San Pedro." Additional work at the base of the breakwater caused the river to be deflected, to discharge in a southeasterly direction ("downcoast"). The delta continued to grow, and a series of improvements were constructed in 1943 - 1945. The river outlet was extended 3,500 ft. seaward "...to the southeast in a long-radius curve by constructing a dike faced with rock riprap." The dike was extended 700 ft. in 1946, and an additional 975 ft. in 1949. The area to the west of the dike was filled with material dredged from the river outlet.

Harbor surging has been a problem in the outer harbor; this is mentioned in the section on *Seiching-Harbor Surging*.

The "Long Beach (Harbor) Breakwater" was damaged by long period waves during 20-24 April 1930. A photograph of the damage, and wave refraction diagrams, are in O'Brien (1947; 1950). [**Note.** This was not what is presently known as the Long Beach Breakwater (Detached), which was built in 1943-1949; or the Middle Breakwater (referred to as the "Outer Breakwater" and also as the "Detached Breakwater" by Horrer), which was built in 1931-1942. The damage event in 1930 caused by waves was prior to the construction of these breakwaters. The locations of the breakwaters are shown in Horrer's Figures 3 and 9.] Wave "hindcasts" were made by Lt. Robert Stump using data from synoptic weather maps of these dates, for a study by O'Brien. O'Brien concluded the waves (long period swell) that caused the damage could not have been generated by the conditions shown on the weather maps. O'Brien, who used refraction diagrams as a part of his study, said: "...At the San Pedro breakwater, only a few miles away there were no breakers and along the shore downcoast (sic, to the southeast) from the Long Beach (sic harbor) breakwater, lifeguards noticed no wave action of unusual intensity." An analysis was made by Horrer (1950) of the likely source of these waves; they were long, low swell in the deep water of the open ocean. He used weather maps and refraction diagrams. Horrer concluded that they must have come from a storm in the southern hemisphere, which are called *southern swell*. His wave refraction diagrams and one of O'Brien's showed the waves were concentrated at the breakwater owing to convergence of wave orthogonals. Horrer said that 20,000 tons of superstructure stone were displaced. For information about *southern swell*, see Wiegel and Kimberley (1950) and Snodgrass, Grove, et al., 1966).

During the "El Nino" (ENSO) winter of 1982-1983 "...Overtopping waves caused a 400-foot (122 meters) long gap," in the San Pedro Breakwater, and other areas of damage. A Corp of Engineers survey "...indicated there were 166 repair areas to the breakwater and that 87 percent of the failures were on the backslope" (Walker, Nathan, Seymour, and Strange III, 1985). These were repaired by the Corps.

During the great storm wave event of 16-18 Jan. 1988, the San Pedro Breakwater "...was breached at two locations. The major breach was 285 ft long, located halfway between the root and the easterly end adjacent to the ship channel (see Domurat and Shak, 1989, 2 photos of damage; Armstrong and Flick, 1989).

The Middle Breakwater (sometimes referred to as the Outer Breakwater) was built in 1932-1942 for the Los Angeles - Long Beach Harbors. It is 18,600 feet long. It has a clay and sand core, covered by rock rubble (Herron, 1986, p. 6-58). There is a gap of 2,100 feet between the San Pedro and the Middle Breakwaters; the entrance of the Main Channel (navigation channel) to the Port of Los Angeles. It is known as Angels Gate. This breakwater was severely damaged by waves of the 24-25 Sept. 1939 tropical storm (hurricane) which reached the coast of southern California, where it dissipated (Horrer, 1950). A photo of a section of the damaged eastern part, and a photo of the relatively undamaged western part are in Horrer's paper. Refracted wave orthogonals and amount of damage to the superstructure along the breakwater are shown in his Figure 9. The effect of refraction by the bathymetry was important; the waves approaching from a southerly direction, where these waves (long period swell) came from, converged at a section of this breakwater. The location of the convergence was very sensitive to the direction from which the waves were coming in the deep open ocean (Horrer, 1950).

The Long Beach (Detached) Breakwater was built in 1943-1949 for protection of the Los Angeles - Long Beach Harbors. It is 13,500 feet long. There is a gap of 1,700 feet between the Middle and the Long Beach Breakwaters. This entrance is known as Queens Gate, and the Long Beach Channel extends between it and the Port of Long Beach.

The total length of the 3 breakwaters, including the 2 gaps for navigation (ship) channels, is 9.2 miles.

The need for an extensive terminal for large deep draft ships resulted in the construction of a new facility for the Port of Los Angeles; Pier 400 (Anon., 2001). It opened in 2002, after many years of planning, environmental studies, design, permitting, and construction. A retaining dyke and fill provide 595 acres of land; with 58 million cu. yds. of fill obtained "...from dredging the new pier's navigation channel from San Pedro Bay" (Jones, Buzzoni, Foxworthy, Menendez, and Shahrestani, 2001; Foxworthy and Alcorn, 2001). There is a container yard, dry bulk and liquid cargo terminals, 6 berths (wharfs), an intermodal yard, buildings and parking. A 7,000 ft. long transportation corridor, with gates, connects it to land; for vehicles, rails (6 tracks), pipelines, and utilities. It has bridges at midway over a navigation channel (Foxworthy and Alcorn, 2001). There are navigation channels, and a turning basin. The entrance channel to the harbor was deepened to 24.7 m, and extended to about 5 km seaward of the harbor entrance channel (which is between the San Pedro and Middle Breakwaters). The dredging included both sand and rocky material. To "...mitigate the effect of the work on fish habitats...," after a study and evaluation, it was decided that much of the rocky material should be used by placing it "...within a man-made fish habitat" (Alcorn and Foxworthy, 2001). This was done.

The *Alameda Corridor*, running parallel to Alameda Street, opened in 2002. According to the Port of

Los Angeles (2008): "...The cornerstone of the Port's intermodal train traffic network is the Alameda Corridor, a $2.5 billion, 20--mile long (32-km) cargo expressway . The corridor serves as the primary connection for cargo-carrying train traffic between the ports of Los Angeles and Long Beach and the transcontinental rail network based near downtown Los Angeles." It is owned by the Alameda Corridor Transportation Authority (AAR) (see also Wikipedia, Alameda Corridor, 2008).

A small pocket beach, manmade, Cabrillo Beach, is on the ocean side of the San Pedro Breakwater, in the corner of the breakwater and shore. It extends 2,400 feet along the breakwater. A short addition was built along shore on the harbor side at a later date. Details are in a subsequent section.

Seiching; Harbor Surging

Seiching (harbor surging) is a problem in Los Angeles and Long Beach Harbors, and in San Pedro Bay. Several studies have been made of it (e.g. Knapp and Vanoni, 1945; Vanoni and Carr, 1951; Carr, 1953; Lee, 1969, 1971; Wilson, 1971; Raichlen, 1971, 1972; Houston, 1977; Herron, 1986; Moffatt & Nichol, Engineers, 2007). A theoretical and a hydraulic model study of wave induced oscillations of the East and West Basins of the Long Beach Harbor (outer harbor) were made by Lee (1969) as part of his investigation. Simplifications were made which included the use of vertical walls, uniform water depth, and periodic waves. The theoretical and hydraulic model results compared favorably. They also compared reasonable well with the results of an earlier study made by Knapp and Vanoni (1945), with a distorted model (vertical/horizontal scales different) for 6-minute (prototype) forcing waves.

Wilson (1971) calculated the natural modes of oscillation of the shelf off San Pedro Bay, based on several assumptions. He pointed out that the shelf was of convex shape, and the contiguous coast concave; and that this was an important feature. He found that the natural periods of oscillation depended on the direction of approach of the long-period forcing waves, but with rather little variation. He found "...that the conical shelf can oscillate in different ways at almost the same periods." Wilson hypothesized a second model, an oceanic basin which included the Channel Islands, and troughs. For a third hypothesized model, transverse oscillations of San Pedro Channel and Continental Shelf, exhibited and interplay of the channel and shelf. Wilson made calculations for several modes of oscillation for each of the models. Many of the periods are close, as can be seen in his tables and graphs, which should be studied closely. Wilson concluded that the "normal periods of oscillations" are: T = 75; 60; 38; 33; 25; 22; 17; etc. minutes. He compared the "natural periods" with energy spectra which he calculated from tide gage records at three stations in Los Angeles-Long Beach Harbors for the tsunamis of 1 April 1946, 23 May 1960, and 28 March 1964; and one station for the 11 Nov. 1922 tsunami (source, Chile). From the comparison, he concluded that the main periods of oscillation shown in the tsunami spectra are in accord with the above sequence. "...The evidence from the power spectra of marigrams of tsunamis registered in Los Angeles - Long Beach Harbors, supports the view that the physical reality of the peaks or energy levels can be interpreted in terms of resonance or near-resonance of modes of oscillation of the continental shelf off San Pedro Bay."

Raichlen (1972), in a Discussion of Wilson's paper, calculated normalized energy density spectra from USC&GS tide gage records for the 23 May 1960 and the 27 March 1964 tsunamis, at 3 locations in southern California; one was at Los Angeles Harbor Berth 60. The spectra for the two events at Berth 60 were quite similar, with two spectral peaks. He referred to the study by Lee (1969), and reproduced one of Lee's figures, the "total velocity" at the Long Beach Harbor entrance a function of the forcing long wave frequency. He said that the figure shows "...the velocity at the entrance for the lowest mode of oscillation (the "pumping" mode, ka = 0.61) is nearly four times that of other higher modes...Using the prototype dimensions for this harbor (a = 6,868 ft and h = 40 ft) the pumping mode is 33 min."

Herron (1986, p. 6-60) commented on the observations he made of strong seiching action in Cerritos Channel during the 23 May 1960 tsunami (source, Chile); with currents of 15 to 18 miles per hour. He said that debris was still sweeping back and forth the following morning when he went to the site again.

Subsidence

Substantial subsidence occurred in the Los Angeles Port/Harbor - Long Beach Port/Harbor and contiguous region, mostly caused by the removal of hydrocarbons from the Wilmington Oil Field, starting in 1928 (e.g., Gilluly and Grant, 1949; Neel, 1957; Allen and Mayuga, 1970; Testa, 1991). Testa (p. 486) said "...Although geodetic leveling surveys established that the coastal area from San Pedro to Seal Beach had been subsiding since the early 1900's, it was not until after this field was developed in the late 1930's that appreciable subsidence was observed." The largest subsidence occurred in the Long Beach Naval Shipyard, about 23 feet by August 1956 (Neel, 1957, his Fig. 7). Testa (p. 482) said that the total subsidence had reached a maximum of about 28 feet, with a subsidence of two feet or more in a 20-square mile area. The Alamitos Bay area subsided from 15-18 inches between 1928 and 1966 (USACE, Los Angeles District (1966/1967). Beginning in 1956, water was reinjected underground in the area, which stabilized most of the affected area by 1966; and "...some areas were beginning to rebound." Subsidence has been halted in some areas, slowed down in others, and elastic "rebound" has occurred is some places owing to the water injection program.

John S. Habel (1978), California State Dept. of Navigation and Ocean Development, wrote a memo about the subsidence in the coastal and offshore region of Surfside-Sunset, Bolsa Chica, Huntington Cliffs, Huntington Beach. He reviewed reports that included beach and bottom profiles measured during a 30-year interval. In comparing these profiles and records of sand replenishment (nourishment), he calculated a net loss "... of about 7 million cu. yds. in the area above the -30 (sic, foot) MLLW contour between the Anaheim Bay jetties and the Santa Ana River." A figure attached to his report (also in USACE, LAD, 1995, p. 20 of Geotechnical Appendix; and in other references), showed estimated subsidence between 1933 and 1964 of from 0.5 foot at Warner Ave., 1 foot near the dam in Bolsa Chica, to 1.5 feet near Huntington Mesa, and up to 4 feet offshore, seaward of the middle of Huntington Mesa. The largest subsidence was in the area of the Huntington Beach New Offshore Field, the Tideland Pool (Barnes, 1945), southwest (offshore) of Bolsa Chica; a maximum of 4.0 feet. Woodward-Clyde Consultants (1986) plotted subsidence data from the Orange County Surveyor's Office, 1976 through 1985. Measurements along Pacific Coast Highway and within the Bolsa Chica wetlands/lowlands are given. The subsidence ranged from 0.002 ft./year at Los Patos (Warner Ave.) to 0.01 ft./year in the middle of the wetlands, to 0.04 ft./year at Huntington Mesa. Both sets of data are in the USACE LAD (Dec. 2002) report. Additional information is in the *Bolsa Chica Lowlands Restoration Project* section.

At the shore, subsidence is manifested by a recession of the shoreline, and offshore as increased water depth. Measurements have shown that the continuous beach along the Huntington Beach Littoral Sediment Sub-cell was substantially wider in 1997 than it was four decades previously, owing to beach nourishment (USACE, LAD, Dec. 2002, Ch. 2 prepared by Coastal Frontiers Corp.; Gadd, Leidersdorf, Hearon, Shak and Ryan, 2007). An important lesson can be learned from the success of this beach nourishment project at a shore that had subsided. It is: one effect of mean sea level rise (from global warming or other cause) can be mitigated. If a beach is valuable, and sufficient beach quality sediment available, an economic solution to beach recession can be to nourish the beach.

Seawater Intrusion into Aquifers, and Its Mitigation

Seawater intrusion into the coastal aquifers has occurred as a result of pumping large quantities of water from wells (or artesian) for use in agriculture, industry, and municipalities. Hydraulic barriers have been constructed and operated to reduce the amount of seawater infiltration (e.g., Ostrom, 1965, Ch. 7; Cho, 2009). The first "barrier" was constructed in the 1950's and two others subsequently, which decreased the amount of seawater that penetrated the aquifers (e.g. Edwards and Evans, 2002). The barriers are sets of closely spaced wells drilled and used "...to inject high quality freshwater into the ground, creating hydraulic pressure ridges or 'barriers' to saltwater intrusion. However, the barriers are not completely effective." The performance of several of the barriers is monitored by the Water Replenishment District of Southern California (WRD); reports are available (e.g., WRD, 2008).

Wave Climate

Wind waves and swell along the coast of the Southern California Bight are complex. They have been categorized as being generated by one of six meteorological patterns. They were described for the Orange County Coast in USACE, Los Angeles District reports (1996; Dec. 2002); and are:

1. Extratropical cyclone of the Northern Hemisphere
2. Northwest winds in the outer coastal waters
3. West to northwest local sea
4. Pre-frontal local sea
5. Tropical storm swell
6. Extratropical cyclone of the Southern Hemisphere

A similar set has been given by Adams, Inman and Graham (2008). They refer to, and describe six "characteristic wave types," and provide an illustration that depicts the locations of the wave generation fetches of each type relative to the Southern California Bight. They attribute the concept to Munk and Traylor (1947) and Arthur, Saur, et al. (1947). Their list of the 6 wave types, which is based on where they are generated is: Aleutian low, Pineapple Express, Northwest swell, Tropical storm, Southern Hemisphere swell, and Local sea breezes. A table in their paper lists values of significant wave height, significant wave period (probably the "spectral peak" period), and direction from which the waves come; at the location 33 deg. N, 121.5 deg. W (an open ocean site west of the Channel Islands). Modal values and the range of data are tabulated for each. The season of the year during which they usually occur is given. Two examples are given of SWAN model-derived maps, color coded, of wave heights within the Southern California Bight. These are for an Aleutian low wave source (wave direction 305 deg.) and for a Pineapple express storm (wave direction 270 deg.), each with a significant wave height of 5 meters, and wave period of 15 seconds.

Wave data from measurements in deep water, or from wave "hindcasting" or "nowcasting" or "forecasting" in the open sea can be transferred to shore using a directional spectral refraction-diffraction model, or a simpler directional spectral refraction model (O'Reilly, 1993; O'Reilly and Guza, 1993; 1998). Maps (values of H/Ho; the model is linear), color coded, of the Southern California Bight for two examples are given by O'Reilly (1993); a hypothesized open ocean narrow directional spectra from 180 deg. true (*southern swell*), and a hypothesized open ocean directional spectra from 270 deg. true (a North Pacific swell event); each with a peak spectral frequency of 0.06 Hertz. Ho is the deep water significant wave height, and H is the significant wave height at each location on the map.

Early studies of wave refraction, and its effect on wave height distributions at Los Angeles/ Long Beach Harbors and vicinity, were made by Gee (1938), O'Brien (1946; 1950, Horrer (1950), USACE, Los Angeles District (1962), and Jen (1969); but these were before the use of spectral inputs had been developed.

Measurements and analyses of ocean waves are a part of the *Coastal Data Information Program*, a joint project of the Scripps Institution of Oceanography of the University of California, the U.S. Army Corps of Engineers, and the California (State) Dept. of Boating and Waterways.

Details of the types of wave gages, their installation and operation, data transmission, analysis, storage, and retrieval are in a paper by Seymour, Castel, McGehee, Thomas, and O'Reilly (1993); an update in Thomas, McGehee, Seymour, and Castel, 1997). Wave data and analyses results are available at http://cdip.ucsd.edu. Wave data are also available from several NOAA National Data Buoy Center buoys at http://www.ndbc.noaa.gov. [**Note**. A 4-gage array (Sxy) was installed at Sunset Beach in about 30 feet of water during Nov. 1980-May 1983 (Patterson, 1988). An Sxy gage was installed at the Huntington Beach Pier in 1990. The author does not know how long these were used. Of historical interest, prior to this program, a step resistance wave gage (on a staff) was installed at the end of the Huntington Beach Pier in 1948 by the USACE Beach Erosion Board, and was operated and maintained until 1965 (Herron, 1986, p. 11-4).]

A list of the larger storms off southern California during 1900-1983, those with significant wave heights greater than 3 m., is in Seymour, Strange III et al. (1984). This study was updated through Spring 1995 by Seymour (1996); it includes the severe storms of the "El Nino" (ENSO) winter of 1982-1983, which have relatively long wave periods as well as being high. The revised list is of "extreme wave episodes," with threshold of significant wave heights increased to those exceeding 4 m. Locally generated wind-wave events were excluded, "...only those episodes where the maximum energy occurred (sic with a wave) period of 12 s or more were included." One hundred and fourteen (114) events are listed, and about 18% of those listed in the 1984 paper were dropped. These are the maximum values measured (or hindcast) in deep water seaward of the Channel Islands. The table lists date, significant wave height (m), maximum wave period (s), and direction (deg. true, "direction from"). T is the "wave period" (1/frequency) at which the wave spectrum peak occurs. [**Note** the relative long values of spectra peak wave periods, compared with those offshore the USA Atlantic and Gulf of Mexico coasts.] The mean directions listed are those at "...the time of the peak of the large wave event." The two most common directions from which the waves came were 270 deg. (true) and 300 deg. (true). Wave directions listed for events that had occurred prior to the installation of directional wave buoys or arrays were obtained from wave hindcasts. The newer wave measurements were from the Begg Rock Buoy, March 1984-Dec. 1986, and the Harvest Platform Array (7-gage array off Point Conception; see Seymour, Castel, et al., 1993 for a description) after 1987. Data prior to installation of wave measurement buoys or arrays were from a combination of "hindcasts" and observations. For an update, see Seymour (2009).

The wave event with the highest significant wave height (10.1 m, wave period 15 sec.) occurred during 16-18 January 1988, and the second highest on 13 March 1905 (significant wave height 8.8 m, 15 sec. period, from 247 deg. true). Owing to a failure of the telephone line at about the peak of the storm, wave data from Begg Rock Buoy ("essentially an open ocean exposure") was interrupted. The significant wave height was about 33.4 feet when the interruption occurred. (Seymour, 1989b). An entire issue of *Shore & Beach* was about the 16-18 Jan. 1988 storm and its effects (e.g., Seymour, 1989 a). Articles in local newspaper describe the storm and damage caused by the waves (e.g., Malnic, 1988). Damage caused by the waves of this storm along the delta's coastline are mentioned in several sections herein. This storm was a "...very intense, fast-moving and compact event." Papers in *Shore & Beach* describe the storm, waves, and coastal sea level (Seymour, 1989 b; Strange III, Graham, and Cayan, 1989; Flick and Badan-Dangoñ, 1989; O'Reilly, 1989). The intensity and the track of the storm relative to the coast were important. According to Strange, Graham, and Cayan (1989) "...Because of their proximity, storms of this type are potentially the most severe storms to impact southern California." They say (p. 7) "...There was a west-northwest swell generated by an earlier more distant storm, already present off southern California as the intensifying storm neared the California coast. The presence of this swell probably allowed more rapid generation of large, long period, swell than would otherwise been possible." Based on a combination of wave measurements and hindcasts provided by N. Graham (of SIO), O'Reilly said "...The peak direction of the spectrum was 280 degrees (270 degrees being directly from the west)... with a peak period of 17 seconds...due to the close proximity of the generation area to southern California, the directional spectrum was quite broad in comparison to the swell from a distant storm."

A half decade prior to this wave event, a series of severe winter storms (1982-1983; an "El Nino", ENSO year) "...caused record damages to the coast of southern California" (Walker, Nathan, Seymour, Strange III, 1985).

What will be the mean wave direction(s), the duration(s), and size(s) of major wave events along the coast of southern California in the future? What will be their effects on the shore, and on structures and infrastructure, and people? This is wanting to know the unknowable. As many things are unpredictable and uncontrollable, sensitivity analyses can be useful in planning for mitigation. How can the risk to people, structures, infrastructure be estimated quantitatively? How can scenarios be devised, used, and evaluated? This must be done with care and good judgement. What are the relative values of mitigation and accommodation? The definition of risk as used herein is that of the National Science and Technology Council (Dec. 2005, p. 23): "The probability of harmful consequences or unexpected losses (death and injury, losses of property and livelihood, economic disruption, or environmental damage) resulting from interactions between natural or human-induced hazards and vulnerable conditions."

Considering what is called "decadal wave climate variability," is useful in helping to understand why caution must be exercised. There are several papers about this (e.g. Walker, Walker, Nathan, Seymour, Strange III, 1985; Seymour, Strange III, Cayan, Castel, 1985; Seymour 1996; Alan and Komar, 2006; Adams, Inman and Graham, 2008). El Nino-Southern Oscillation (ENSO) episodes are of major importance in regard to the wave climate, and several papers are available about them (e.g., Seymour, Strange III, et al., 1985, Seymour, 1996; 1998; 2009).

Storm surges occur along the coast of southern California. They are not as high or as important as along the Atlantic and Gulf of Mexico coasts of the USA, but must be considered (Flick, 1993). Monthly mean sea levels have increased during ENSO events (Flick, 1998). Wave set-up is important in southern California. Storm surge, wave set-up, and wave-runup, together with estimates of change in relative mean sea level must be included in risk evaluation scenarios (USACE, Los Angeles District, Dec. 2002; Walker, Nathan, Seymour, Strange III, 1985).

Owing to coastal flooding that has occurred along the Orange County Coast, a section of the USACE, Los Angeles District report (Dec. 2002, Chapter 6) is *Flooding By Waves and Tides*. The history of coastal flooding and mitigation procedures are described. Monte Carlo simulations were used to calculate flooding for various scenarios; combinations of water levels (astronomical tides, storm surges, wave set-ups), wave characteristics, beach profiles, wave runups, beach berm elevations, berms constructed of sand during the winter for protection.

Cabrillo County Beach

Cabrillo County Beach is a manmade small pocket beach (about 2,400 feet long) on the seaward side of the San Pedro Breakwater, in the corner formed by the breakwater and shore (USACE, Los Angeles District, 1950; Price, 1966; Herron, 1980; Dunham, 1986; Flick, 1993). The beach is a little east of Pt. Fermin. Information about it is in the video *Lost and Found: Beach Renourishment in L.A. County* by the Los Angeles County Dept. of Beaches and Harbors (1992). Early attempts to build a beach here were in 1927, with 500,000 cu. yds. of material placed; and in 1948, with 2.9 million cu. yds. obtained from a dredging project of the Los Angeles outer harbor (USACE, Los Angeles District, 1950; 1989). Its southeastern terminus, on the breakwater, and normal to it, is an impermeable rubblemound groin about 750 ft. long, completed in Dec. 1962. A 1962 aerial photo looking from offshore over the beach, breakwater, and Los Angeles Port/Harbor is in Herron (1980). The beach was severely eroded during the great storm wave event of 16-18 Jan. 1988. "...The parking lot pavement was scoured away, and the entire area was littered with rocks, and cobble displaced and carried on shore from the rock-rubble revetment" (Armstrong and Flick, 1989). A photo showing the damage is in the paper.

In 1991, 200,000 cu. yds. were brought by truck from the Hyperion Treatment facility work that was being done ("sand of opportunity") and placed on the beach (L.A. County Dept. Beaches and Harbors, 1992). An aerial photo taken at a later date (Anon, 2001) shows the beach; and also a small beach on the shore on the harbor side of the breakwater, sometimes referred to as the inner Cabrillo Beach. Both beaches can be seen in a vertical aerial photo of Google Maps (2009). [**Notes. 1)** the author has not been able to find out when, or by whom, the beach inside the harbor was made; but it was made of material dredged in the port (Marroquin, 2009). **2)** 85,000 cu. yds. of sand were taken by truck in 2008 from the harbor side beach, and replaced with 85,000 cu. yds. of coarser sand from a quarry. 30,000 cu. yds. were placed on the beach in April 2009 (Ryan, 2009). **3)** "A second sand-replacement project for the beach's low tide area was completed in June (sic 2009). In total, port officials have replaced 130,000 tons of sand at Cabrillo Beach, said Arley Baker, the port's (sic. Port of Los Angeles) deputy executive director of communications" (Marroquin, 2009). **4)** Of historical interest is the fact that one of the earliest uses of a wave refraction diagram was part of the hydraulic model study of this beach made by Gee (1938), in his M.S. thesis at the University of California, Berkeley, CA, under the supervision of Professor Morrough P. O'Brien.]

Windsurfing is popular offshore Cabrillo Beach, both on the ocean side and within the harbor side. It is sometimes called "Hurricane Gulch."

Long Beach and Belmont Shore Beaches

As a prelude to this section, it is instructive to refer to observations made during what must have been a *southern swell* event on 21-25 August 1934 (McEwen, 1935). Most of the damage was done in the Newport-Balboa Beach region, and is described in a subsequent section of this report. Damage was done in Long Beach, along the rock breakwater in the Rainbow Pier area. McEwen (1935) said "...Huge rollers were breaking one thousand feet off the shore... "enormous waves continued to pour over the top of the pier...A great quantity of sand was gouged out of the beaches and carried to sea."

Herron (1986, p. 6-63) said that following the cutoff of sand from the Los Angeles River, the beach at Long Beach eroded/ receded. He said there was no beach at high tide -- until after World War II, when sediment was dredged from the Los Angeles River delta in Long Beach and placed along the shore from "Rainbow Pier" to about Belmont Pier. In 1945-1946 about 1,200,000 cubic yards of material dredged from the Los Angeles River delta were pumped to the Belmont segment and placed on the beach (U.S. Congress, 1954, pp. 10-11). In 1946 the city of Long Beach placed about 628,000 cu. yds. of material dredged from Alamitos Bay along the "peninsula section." Since completion of the Long Beach detached breakwater in 1949. the beach at Long Beach and Belmont Shore has been in the lee of the structure. In 1950, the city deposited about 540,000 cu. yds. of material dredged from the bay and its entrance (U.S. Congress, 1954). Oblique aerial photos show the "peninsula section" in 1921, 1940, and 1964, Figures 5, 6, and 7.

[**Note.** The one-mile long section of beach from the Belmont Pier, southeast to the base of the peninsula, is known as Belmont Shore, or sometimes as the "Belmont Section." The section of beach on the ocean side of the *Alamitos Bay Peninsula* is known variously as Belmont Shore Beach, or East Long Beach Shoreline, or the Peninsula Section. This peninsula (a narrow sand spit) is northwest of the "west" jetty of the Alamitos Bay entrance. It is a little more than one mile in length, Figures 6 and 7.]

Nathan (1994) wrote the "East Long Beach shoreline" had erosion (sic, recession) rates that "...ranged from 7 feet per year to as much as 50 feet per year since 1957." The sediment for the beach nourishment in the 1950's, 1960's and 1970's was from dredging in Alamitos Bay, and its entrance, and the San Gabriel River mouth. Nathan (1994) said: "...The majority of the grain size sand was smaller than required to sustain a stable beach for the local wave climate and the beach continued to erode." He added that in 1980, a combination of material was used: dredged material (about 0.16 mm grain size) on the inland section of the berm, and 2.6 mm ("pea gravel") size on the sea-side of the berm and beach face (with a 1:5 slope); but it eroded. In 1983, "artificial seaweed" (plastic) was placed parallel to shore, and 300,000 cu. yds. of sediment placed on the beach. The "seaweed" was not effective. Additional "seaweed" was placed in 1985, 1987, and 1990, which "...eventually broke loose;" it became scattered or buried. In 1992, the city installed a 300-ft. long shore-parallel "sandbag reef"; a detached submerged breakwater. It was in a water depth of -3 ft. to -4 ft. MLLW, with the top at +2 ft. MLLW. Nathan said it was observed that "...water ponding on the landward side of the reef created a return flow seaward around the ends," which caused scouring. The city removed the top layer of sand bags to decrease the ponding.

[**Note.** For more details about the problem of ponding between a shore-parallel submerged artificial reef and shore, by wave overtopping; and the resulting littoral currents and erosion of the beach, see the paper by Dean, Chen, and Browder (2007). Details are provided of a 23-month monitoring program of the experimental 1,260 m. long structure at Palm Beach, Florida.]

Studies are being made for the City of Long Beach by Moffatt & Nichol Engineers about the effects on the water quality, waves, and the beach, if changes were to be made (hypothesized scenarios) to the Long Beach (Detached) Breakwater; reconfiguration - length, orientation, lowering the crest to beneath the surface, etc. (Boudreau, 2009; Sahagun, 2009).

Seal Beach

The beach at the city of Seal Beach is between the San Gabriel River east jetty and the Anaheim Bay west jetty; it is about 1 mile in length. The beach has been affected by the change in wave conditions at the shore caused by the Long Beach (Detached) Breakwater, since the breakwater was built in 1943-1949. The direction of the net alongshore transport of sand shifted in this section after the breakwater was built, and became SE to NW (Herron, 1986). About 800,000 cu. yd. of sand were placed along the shore in 1944 and 1945-1946; the material was obtained from dredging the Alamitos Bay entrance channel (Kenyon, Jr., 1951). A 1958 aerial photo in Dorr (1976, p. 31) shows the beach with almost no sand. A 750-foot long concrete groin was built along the west side of the pier in 1959; and the beach became essentially two compartments. This was based on a recommendation by the Corps' in their report to Congress (U.S. Congress, 1954, p. 43). The groin extended from shore to the -11 ft. depth contour. Prestressed concrete sheet piles were used, with H-beam whalers along the top edge of the piles, with a concrete cap poured in place (Herron, 1986). The beach was nourished in 1959; 248,000 cu. yds. of material dredged from Anaheim Bay and 225,000 cubic yards of sand dredged from the San Gabriel River. 70,000 cu. yds. of material were dredged in 1967 from the San Gabriel River, and placed on the beach. 250,000 cu. yds. of sediment from the Naval Weapons Station were placed on the beach in 1983, a part of Stage 8 (D.R. Patterson, 1988).

Backpassing of sand from "West Beach" to "East Beach" has been done on occasions (e.g., 130,000 cu. yds. in 1969; 33,400 cu. yds. in 1972). Sand has also been backpassed within West Beach (e.g., 8,500 cu. yds. in 1973). The alongshore transport of sand from "East Beach" to "West Beach" is an ongoing problem; the net movement is from southeast to northwest. It accumulates at the northwesterly end of the "West Beach" at the San Gabriel River mouth east jetty. The City of Seal Beach "backpass" about 50,000 cu. yds. of sand about every 3 years from the "West Beach" to the "East Beach," as needed (Walker and Brodeur, 1993; Boudreau, Aug. 2009). They also place a sand bag berm each winter on the beach berm for protection from flooding by storm wave-runup (USACE, Los Angeles District, Dec. 2002, Fig. 6-1; Boudreau, Aug. 2009).

Severe erosion/recession of West Beach occurred during the great storm wave event of 16-18 Jan. 1988. The sheet pile groin along the pier was damaged. The 8th Street parking lot was overwashed and damaged. "...The restrooms landward of the parking lot were flooded"...but "...no major flooding occurred between the pier and the west Anaheim Bay jetty (sic, East Beach) (Armstrong and Flick, 1989).

55,000 cu. yds. of material dredged from the channel to NWS Seal Beach, at Anaheim Bay, were placed on the East Beach by the Corps' Stage 12 in early 2009 (Ryan, 2009).

Surfside-Sunset, Bolsa Chica, Huntington Cliffs, Huntington Beach; Beach Nourishment

The Surfside-Sunset Beach Nourishment Project, which is described below, was one of the projects awarded the *2007 Top Restored Beach Award* by the American Shore and Beach Preservation Association (ASBPA) (Higgins, 2008).

An extensive beach erosion study of the beach between the Anaheim Bay entrance and the Santa Ana River mouth, and adjacent beaches was made in 1939. A report on the work is in a letter to the U.S. Congress from the Chief of Engineers, U.S. Army (U.S. Congress, 1940). A "post WWII" (probably late 1940's) aerial photo of Surfside Beach in the foreground, looking SE from above the southeast jetty of Anaheim Bay is Figure 8. Compare this with a 1998 aerial photo of the same section of coast, looking toward the NE from offshore, Figure 9. Surfside Beach is on the left and Sunset Beach at the center. The increase in beach width is the result of the beach nourishments, as described below.

A combination of the change in the supply of sand to the beach "downdrift" (southeast) of the Anaheim Bay entrance jetties, encroaching on the beach and dunes by the building of beachhouses in the Surfside-Sunset area, and ground subsidence owing to oil, gas, and water withdrawal from subsurface reservoirs, resulted in erosion/ recession of the 12-mile long beach starting at the base of the southeast jetty. The Corps' report (1940) to the U.S. Congress includes the following statement: "...In his report submitting field data and observations to the Board (sic, Beach Erosion Board), the district engineer concludes that the diminution of supply of river sand by the construction of flood-control works will necessitate protective measures to prevent denudation of the beaches." The first source of sediment placed at Surfside Beach was from dredging for navigation requirements at the U.S. Navy Seal Beach Naval Ammunition and Net Depot that was established in Anaheim Bay during World War II); in 1945, 1947, and 1952. This depot subsequently became the U.S. Naval Weapons Station Seal Beach. A short groin was built at Surfside Beach at the jetty base by the U.S. Navy (USACE, Los Angeles District, as given in Wiegel, 1994).

A beach erosion control study was made of the San Gabriel River to Newport Bay section of coast by the Corps' and reported to U.S. Congress (USACE, Los Angeles District, 1962; U.S. Congress, 1962). The history of beach nourishment requirements and accomplishments in this littoral sediment cell prior to 1962 is in the Corps' report; and recommendations given for an erosion control project. Data are also in a paper by D.R. Patterson (1988).

Shak and Ryan said: "...The U.S. Congress authorized an erosion control project in 1962, recognizing the impacts of flood works, coastal harbors and other factors in causing beach erosion along the northern Orange County, California shoreline." The first placement of beach nourishment sediment at Surfside-Sunset that was a part of this program was in 1964 (Stage 1). The most recent was in mid-2009 (Stage 12). The nourishments have been made in an approximate 5-year cycle. Beach replenishment with placements of sediment on Surfside-Sunset had been made prior to the present program. An assessment of the regional coastal processes and evaluation of effects of the beach nourishment through many decades are in the report *California Storm and Tidal Wave Study, South Coast Region, Orange County* by the USACE, Los Angeles District (Dec. 2002); and of the present program in papers by Shak and Ryan (1997), and by Gadd, Leidersdorf, Hearon, Shak and Ryan (2007). [**Note.** The author participated in working meetings on the report preparation (e.g. Wiegel, 1996); and reviewed the Corps' draft report for Orange County (Wiegel, 2002).]

The sources of beach replenishment sediment since the start of the present project in 1963 were navigation projects, and dredging from offshore "dredge pits" (also called "offshore borrow pits"). Locations of several of the offshore borrow pits are shown in Figure 10. The "feeder beach" was Surfside-Sunset, just southeast of the Anaheim Bay SE entrance (arrowhead) jetty. Owing to the local wave climate, the net movement of sand alongshore in this region is toward the southeast, and sand has been transported by wave action to, and distributed along, Surfside Beach, Sunset County Beach, Bolsa Chica State Beach, Huntington Cliffs, and Huntington Beach to the mouth of the Santa Ana River. Some sections of the beach are backed by low sea cliffs (bluffs) of mesas; and some sediment is supplied to the beach from their erosion (e.g. Patsch and Griggs, 2005).

<u>Beach Nourishment Placements (Beach Fills) at Surfside-Sunset Since 1964</u>

(From USACE, Los Angeles District, Dec. 2002; Shak and Ryan, 1997; Gadd, Leidersdorf, Hearon, Shak and Ryan, 2007; Ryan, 2008; 2009):

1964, June, dredge volume 4,000,000 cubic yards, cumulative volume 4,000,000 cubic yards. (Stage 1, dredged from Anaheim Bay)
1971, May, 2,260,000 cy, cum. vol. 6,260,000 cy (Stage 4A, dredged from Anaheim Bay)
1979, June, 1,644,000 cy, cum. vol. 7,904,000 cy (Stage 7, from offshore borrow areas)
1983, May, 400,000 cy, cum. vol. 8,304,000 cy (deepening NWS channel)
1984, April,1,500,000 cy, cum. vol. 9,804,000 cy (Stage 8, offshore borrow areas)
1984, April, 783,000 cy, cum. vol. 10,587,000 cy (Seal Beach NWS)
1989, March, 180,000 cy, cum. vol. 10,767,000 cy. (deepening NWS channel)
1990, June, 1,300,000 cy, cum. vol. 12,067,000 cy. (Stage 9, offshore borrow areas)
1990, Sept., 522,000 cy, cum. vol. 12,589,000 cy. (Stage 9, offshore borrow areas)
1996, Nov. to July 1997, 1,600,000 cy, cum. vol. 14,189,000 cy. (Stage 10, offshore borrow areas)
2002, 2,233,000 cy, cum. vol. 16,422,000 cy (Stage 11)
2009, June, 1,000,000 cy, cum. vol. 17,422,000 cy (Stage 12. offshore borrow areas)
250,000 cy, cum. vol. 17,672,000 cy (Stage 12, offshore borrow areas)
250,000 cy, cum. vol. 17,922.000 cy (Stage 12, offshore borrow areas)

Many surveys have been made along beach profiles in the Huntington Beach Littoral Sediment Sub-cell between Anaheim Bay entrance and the Santa Ana River mouth jetties. Locations of the survey transects are shown in Figure 10. Surveys included condition surveys, pre- and post construction surveys, CCSTWS surveys, NOS (U.S. National Ocean Survey), Santa Ana River Mainstem (SAR) project surveys, with varying spatial coverage, resolution, and duration; they are listed in Shak and Ryan (1997) and the USACE, Los Angeles District report (Dec. 2002). The survey data were used to construct Triangulated Irregular Network (TIN) models (also referred to as digital terrain models, DTM). Shak and Ryan (1997) said that "...pre-project levels, protective beach widths are not always provided for all locations. This is particularly true for about the 3,000 feet adjacent to the Anaheim Bay east jetty." They thought this was a result of wave reflections from the 1,150 ft. long arrowhead jetty. [**Note.** Herron (1986, p. 7-12) said; "...The situation on the east jetty was quite different.

Because of the angle of the arrowhead jetties, this area was able to completely and freely receive the normal offshore wave action and full rates of littoral drift was resumed. But the angle with which these waves approached the jetty was so slight that there was not a clean reflection; rather there was a pile up of water along the jetty as the wave travelled along its length and developed what some engineers have identified as a "mach stem" effect. Instead of reflected wave energies, the energies accumulated in the first 100 to 150 feet of the wave against the jetty. This does have a very pronounced effect as this reinforced wave reaches the beach. Erosion is accelerated and it tended to cut out a pocket right at the base of the jetty The Navy built a short step groin to try to break up this effect, but, if it succeeded at all, it has been a very minor success." See Wiegel (1964) about Mach-stem/ reflection.]

The time history of beach nourishment placement volume (in millions of cubic yards) versus date (1963-1997) is shown in Figure 11 (from USACE, LAD, Dec. 2002; Gadd, Leidersdorf et al., 2007). Also plotted are beach nourishment volume less 20% fines, surveyed shorezone volume (to statistical depth of closure), and surveyed subaerial volume to MSL (mean sea level). The *shorezone volume* was defined as: "...the volume of sediment lying between the back beach and an offshore boundary representing the seaward limit of statistically significant profile data (referred to as the point of *statistical closure*)." This includes the subaerial volume of the beach, Figure 12. The concept and technique for obtaining estimates of the statistical depth of closure were refined for use in the CCSTWS study. They are described in the CCSTWS report (Dec. 2002) and in Gadd, Leidersdorf, Hearon, Shak, and Ryan (2007). They emphasize "...these depths do not necessarily fulfill the definition of physical closure..." "...Instead, they are intended to approximate the seaward boundary of the data that can be used with a high degree of confidence in computing volume changes." They found that for the entire littoral sediment sub-cell of Surfside-Sunset to the Santa Ana River mouth, "...the 1963-1997 period was marked by an average increase in beach width of 4.1 ft/year and a corresponding shorezone unit volume increase of 4.7 cy/ft/year." The authors concluded that the "...nourishment programs have exerted a substantial positive impact on the beaches of the Huntington Beach Littoral (sic Sediment) Sub-cell." Depths of *statistical closure* along the Huntington Beach Sediment Sub-cell (including the West Newport Beach sub-cell) are plotted in Figure 13 (from USACE, LAD, Dec. 2002; Gadd, Leidersdorf, et al., 2007).

In addition to beach profile surveys, use was made of *Clancy beach width* data obtained by the late Robert M. Clancy, and subsequently by Chuck Mesa, both of the USACE, Los Angeles District. This is the measured width of a beach from a consistent, easily identifiable back-beach location to the seaward edge of the beach berm (Clancy, Camfield, and Schneider, 1983). It is a useful, and inexpensive means of monitoring what most beach-users consider to be "the beach." The measurements were made at 25 stations, starting in 1977. Data sets for many locations and dates are given in the USACE, Los Angeles District report (Dec. 2002), and compared with survey data. Clancy beach widths were found to correlate reasonable well with beach profile survey data of Mean Sea Level (MSL) beach widths. A location map and photos of the Surfside, Bolsa Chica, Huntington Cliffs, Huntington Beach region are in Clancy, Camfield, and Schneider (1983).

[**Note.** During the *California Coastal Storm and Tidal Wave Study* (CCSTWS) of the Orange County Coast by the USACE Los Angeles District, it was concluded that about 20% of the dredged sediment placed on the feeder beach was too fine to remain on the beach. This was based on an examination of coring records from the offshore borrow pits. The remaining sediment, "beach-quality sediment" (sand) remains on the beach and in the nearshore, shoreward of the *statistical depth of closure* (Gadd, Leidersdorf, Hearon, Shak and Ryan, 2007). It is useful to refer to the study of Limber, Patsch, and Griggs (2008) about coastal sediment budgets and the littoral cutoff diameter (LCD); to determine whether fine sand being delivered to the coastline is littoral type (i.e., coarser than the LCD). One of their conclusions was "... overestimates of contributing littoral sand are more pronounced in sediment sources that contain large fractions of fine sand, such as (sic, rivers)... and eroding sea cliffs of San Pedro and Santa Monica littoral cells. In these cases, possible overestimation ranges from 57% to 300%, and the large discrepancy has significant implications for quantifying sand inputs to California's beaches." They say there is a "...minimum grain size threshold, termed the littoral cutoff diameter..." and that "...sediment contributed to the littoral system that is smaller than this threshold, even if defined as sand by the Wentworth Scale, may not remain on the beach in any significant quantity." It is probably deposited offshore. A table of values of LCD's for many of the California littoral sediment cells is in their paper. A common value along much of California's coast is 125 microns (0.125 mm). It appears to be a function of wave energy; the greater the annual wave energy, the larger the LCD. The value given for the San Pedro Littoral Cell (seacliff erosion) is 105 microns (0.105 mm). The grain sizes were obtained by sieve analyses of sediment samples; median grains sizes reported.]

It is important to consider the "storm of record," the most intense wave event in the Southern California Bight during the past century, which occurred on 16-18 Jan. 1988 (e.g., Seymour, 1989; 1996). In their investigation of the damage along the southern California shoreline caused by this event, Armstrong and Flick (1989) said "...The Surfside/Sunset Beach area did not have any structural damage to beach front homes, although the outer sand dike, constructed each winter to reduce wave overwash, was breached at numerous locations and was entirely obliterated toward the southern Sunset Beach, near Warner Avenue." They said the Huntington Beach Pier was severely damaged; that the pier end 250 feet "...along with 'The End' Cafe, collapsed and was washed away when waves exceeding 18 feet broke over it." A photo of the remaining end of the pier, dated 20 Jan. 1988, is in their paper. The entire length of Bolsa Chica State Beach was overwashed, and the restrooms flooded and the floors covered with sand. The "...Pacific Coast Highway from Warner Avenue to the bluff area was closed due to flooding from 17 to 19 January (Armstrong and Flick, 1989).

Newport Beach (West), and Balboa Beach; Newport Bay

[**Note.** Of historic interest is the comment of U.S. Coast Survey Assistant W.E. Greenwell in 1861 about the Newport Estuary/Lagoon entrance; "...The outlet or mouth is fifty yards in width, with a narrow bar outside...Over this bar there is a frightful swell rolling and tumbling at all stages of the tide, making it dangerous to cross in boats of any kind." See Fig. 14; a 1878 map]

Newport Bay is relatively small. Its tidal prism (between MLLW and MHHW) vs. entrance area (below MSL) is 2.0 x 10^8 cubic feet vs. 6.0 x 10^3 square feet (e.g., Wiegel, 1964, p. 380; O'Brien, 1967). The entrance channel to Newport Bay, adjacent to Corona del Mar bluffs, was "... improved by construction in 1919 of a stone jetty 1,950 feet in length on the west side of the channel. An extension 200 feet seaward, to a 22-foot depth of water was made in 1920. The jetty was repaired and strengthened in 1920 and 1927 " (Patterson and Williamson, 1960), Fig. 15. A concrete sheet pile jetty, 720 ft. long, was built on the east side of the entrance in 1928. Additional work on the jetties and channel dredging was done, such as repair after damage by the hurricane waves in 1939 (USACE Los Angeles District, Dec. 2002). The entrance was dredged in 1960 (Shaw, 1980). Photos taken before, during, and after construction of the jetties are in Lee (1973). A 1995 aerial photo is Fig. 16.

As mentioned previously, the Santa Ana River has flowed into the ocean at various locations. One of the locations was into Newport Bay/Lagoon, with the entrance to the ocean at or near the Corona del Mar bluffs, Figure 4 (e.g. Patterson and Williamson, 1960; Everts Coastal, 1996). In 1860, U.S. Coast Survey Assistant Greenwell observed (p. 66) that the narrow sand spit (Balboa Peninsula/Beach) was low "...over which the heavy southeast and northwest swells wash in every great gale." In 1920, after a major flood, the river was diverted directly into the ocean, by construction of the Bitter Point Dam, the river mouth jetties, and associated flood control works by Orange County. The river no longer flowed into Newport Bay. The jetties were 520 ft. apart; the west jetty was 700 ft. long, and the east jetty 350 ft. The outlet location is shown on Figure 3. Additional work was done on the jetties in 1935. The east jetty was extended to a length of 700 ft. in 1959 (Patterson and Williamson, 1960).

Between 1916 and 1934, mud flats and sand bars were dredged as part of the development of Newport Harbor, and marinas in the bay; navigation channels were dredged. Dredged material was placed on tide marshes to create two islands, to increase the elevation of the dangerously low sparsely populated Balboa Island and Lido Isle. These were for home sites, and for berths/boat slips along the island perimeters. Aerial photos taken in May 1923 and April 1928 show "before" and "after" of Balboa Island and the bay entrance (Patterson and Williamson (1960). Reclamation of adjacent lowlands and several small islands within the bay was also done (U.S. Congress, Senate Committee on Commerce, 1936-1937); see Fig. 15.

Large quantities of the dredged material were placed on the ocean beaches of West Newport and Balboa Beach to increase their elevation and width. Patterson and Williamson (1960) say: "...Between 1916 and 1932, 1,600,000 cubic yards of dredged material were placed along the beach during initial improvement of the bay by local interests. In 1934-35 an additional 7,400,000 cubic yards were deposited in conjunction with harbor improvements carried out by the Corps of Engineers in a joint project with Orange County." The material was very coarse sand with some shells and a small amount of silt. In a Corps' report to the U.S. Congress (1940, paragraphs 68 and 69) it is stated that 5,600,000 cubic yards of sediment were placed in 1934-1935 between the Newport Bay entrance west jetty and Newport Pier. Also, the beach (West Newport) between the Newport Pier and the Santa Ana River mouth was widened. 1,900,000 cu. yds. of material were placed along about 7,000 ft. of the beach, between the pier and 46th Street. A survey in 1936 indicated that "...wave action and ocean currents had distributed about 400,000 cu. yds. of the material..." from 46th St. to the river mouth. [**Note.** A map/plan in the report shows 46th Street at that time was at the boundary of the beach lots. Also, there was, and is, a change in shoreline orientation at about this section. The net littoral transport of sand toward the northwest in this section of beach has continued.]

A cooperative project (local interests and the federal government) for Newport Bay, California adopted in 1934, was completed in 1934-1935, according to U.S. Congress, Senate Committee on Commerce (1936/1937, p. 1). This project "... provided for the extension of the east and west entrance jetties to lengths of 1,620 and 2,860 feet, respectively, and the dredging of the main channels and turning basin to a depth of 20 feet, with widths of 500 feet through the entrance and generally 200 feet inside the bay, a yacht anchorage 1,200 feet wide and 1,700 feet long midway of the bay to a depth of 15 feet, and the remainder of the bay to a depth of 10 feet." (See also Patterson and Williamson, 1960). Patterson and Williamson (1960) said that owing to the bearing of the west jetty being South 15 deg. east, large waves from the south-southwest "...struck the jetty at an angle, raced along its seaward side, and created a backwash which scoured the shore at the jetty's base."[**Note.** See comment at end of this section about the surf-break, *The Wedge*, at the base of the jetty.] In 1930, a stone groin was built at right angles to the jetty a little offshore, and another groin 400 feet westerly of the west jetty, to mitigate for the beach erosion.

Destructive high waves have occurred at the shore on occasions during the summer, which were likely to have been what is known as *southern swell*. [For an explanation of *southern swell*, see Wiegel and Kimberley (1950); Snodgrass, Groves, Hasselmann, Miller, Munk, Powers, 1966).] Two events were described by McEwen (1935); 21-25 August 1934 and 4-7 September 1934. McEwen said about the 21-25 Aug. 1934 event: "...Balboa streets were flooded,...large deposits of sand were washed shoreward and settled on highways, and a score of cottages were badly damaged... for a while the whole beach frontage between Balboa and Newport was threatened with destruction." He said: "...during a period of light winds or calms...waves of a reported height exceeding 30 feet broke with tremendous force along the coast from Laguna to Malibu...At sea the swells were from three hundred to five hundred meters in length and three to five meters in height." [**Note**. In deep water, the swell which would have had a narrow spectrum, would have had a "period" of 13.5 to 17.5 seconds.] McEwen said about the 4-7 Sept. 1934 event; "...Newport Beach and Balboa Beach suffered even greater damage than during the August... At Newport Beach high waves carried away six electric light poles...several blocks of summer homes in west Newport remained perched unsteadily above the surf on slender piles, and a great quantity of the beach sand was washed from underneath...two houses and a garage were carried out to sea and wrecked, and passage of Pacific Electric trains was hampered near Newport by undermining of the tracks in some places." Twenty-five years later, Patterson and Williamson (1960) wrote: "...A severe ocean storm occurring in the fall of 1934 moved the shoreline in the vicinity of 36th Street landward by as much as 150 feet...," and "...since the harbor construction in the middle thirties, there have been no ocean storms to compare with that experienced in 1934." Spencer (1985) said there was little effects of storm waves at West Newport Beach during 1940-1964, but in August 1965 "tropical storm waves" caused erosion/ recession of the beach. A photo taken on 23 Aug. 1965 shows an escarpment that formed, looking northwesterly from 37th St. A photo taken on 27 Aug. 1965 shows sand bags being placed on the "sloped" escarpment, a few feet in front of the beach-homes, looking southeasterly from about 38th St. Spencer said: "...The same situation occurred in 1966, and again in 1967, when the berm edge receded to the residential property line between 36th Street and 43rd Street." [**Note**. It would be useful to analyze these events in a manner similar to what was done by O'Brien (1947, 1950) and by Horrer (1950) for the wave event in 1930; but using the wave spectra refraction analysis of O'Reilly (1993). Refraction diagrams (for periodic waves) for six cases are in Spencer (1985): T = 16 sec., coming from open ocean directions of 180 deg. and 270 deg. true; T = 8 and 10 seconds, each from 170 deg. and 250 deg. true. These were prepared at the USACE Waterways Experiment Station]

The "storm of record", the most intense wave event in the Southern California Bight occurred on 16-18 Jan. 1988 (e.g., Seymour, 1989; 1996). In their investigation of storm damage along the coast of California, Armstrong and Flick (1989) wrote: "...The beach at Newport between Santa Ana River and the Newport Pier was overwashed. No residences were flooded, but parking lots were covered with sand and debris, and the parking lot south of the Safety Headquarters was washed away." They said the Newport Pier had only minor damage, and the Balboa Pier was not damaged.

Good surfing waves (body-surfing and surfboarding) occur just off the beach at the side of the west jetty. It is known as *The Wedge*. For safety, only body-surfing is permitted at this surf-break from 10:00 a.m. until 5:00 p.m. during the summer (e.g., Brandt, 2006; Beach California.com, 2009). The best waves for surfing are the long-period *southern swell* arriving from the southern hemisphere in the summer. From what the author has read, and heard, this is probably a *Mach-stem* "reflection" along the structure; for some information about this phenomenon see Wiegel (1964); Memita and Sakai (2004; 2005).

West Newport Beach and Balboa Beach (Peninsula) were included in the beach erosion control project authorized by U.S. Congress in 1962. Eight groins were built during 1968 - 1973 on West Newport Beach, between 28th and 56th Streets. Three were of steel sheetpiles, subsequently encased in rubble and extended in length; five were rubblemound. Locations, lengths, and photos are in the USACE, LAD (Dec. 2002) report; see Fig. 17 for locations. The groin field was filled by placement of sediment, and renourished on several occasions. The material was from three sources: "backpassed" from Balboa Beach/Peninsula (which is about 2.8 miles long), the Santa Ana River channel, and "backpassed" from the section of beach at and near the river mouth. The history of nourishment is in the table below. (Some of this information is from USACE, Los Angeles District, as given in Wiegel, 1994; Hillyer, 1996; recent data from Ryan, 2009.)

Beach Nourishment of West Newport Beach Since 1965

1965; 124,000 cy, from Balboa Peninsula
1966; 60,000 cy, from Balboa Peninsula
1967; 150,000 cy, from Balboa Peninsula
1968; 435,000 cy, from Balboa Peninsula, Stage 2
1968; 246,000 cy, from Santa Ana River, Stage 2
1969; 750,000 cy, from Santa Ana River, Stage 3
1970; 124,000 cy, from Santa Ana River, Stage 3
1973; 350,000 cy, from Santa Ana River, Stage 4b and 5
1992; 1,300,000 cy, from Santa Ana River
2009; 100,000 cy, from beach near Santa Ana River mouth, Stage 12

[**Notes. [1)** Stage 6 was deferred. **2)** In the 1992 placement of 1,300,000 cubic yards, the material was obtained from the Santa Ana River, the "Mainstream Project," and placed offshore in a "narrow mound; a mix of silt and mud (17%), sand (80%), and some cobble-size angular rock", USACE, LAD, Dec. 2002). The material was placed in water depths of -5 to -20 feet below MLLW, seaward of the section of beach between the river mouth and the groin field. A major purpose of this project was to determine its capability as a beach nourishment technique, and has been monitored (Mesa, 1997). An additional benefit for a few years was its popularity with surfers as a surfing-break. **3)** In 2009 sand was moved by scraper from where it had accumulated along the northwesterly end of West Newport Beach, between 58th St. and the Santa Ana River Mouth (County) Beach; and placed between the 46th St. jetty and the 28th St. jetty (Ryan, 2009); for locations see Fig. 17.]

Bolsa Chica Lowlands, and the Restoration Project

The *Bolsa Chica Lowlands Restoration Project* was completed in 2006 (Flaccus, 2006). It is on approximately 880 acres acquired from Signal Bolsa Corp. in Feb. 1997, with title by the California States Lands Commission. A contribution of $78.75 million from the Long Beach and Los Angeles Ports in exchange for 520 acres of "...mitigation credit for port landfill and construction, was used in the acquisition and restoration" (California Coastal Commission, 2001/2002, p. 4). Kiewit Pacific Co. was the construction contractor, and Moffatt & Nichol Engineers the construction manager. The contracts were awarded on 1 Sept. 2004 (nearly $64 million) by the U.S. Fish & Wildlife Service (U.S. Fish & Wildlife Service, 2004). Construction began in Nov. 2004, and the work was completed in 2006. Some details of the construction are in an article in *Civil Engineering* (Hansen, 2005). Bolsa Chica State Beach extends along the ocean shore in this area, with the 4-lane Pacific Coast Highway between the beach and the Lowlands. In 2008 this project received the first Project Excellence Award of the ASCE's Coasts, Oceans, Ports, and Rivers Institute (ASCE COPRI, 2009).

Prior to 1899, Bolsa Chica Bay was an estuary, with its ocean entrance through a sand spit which was normally open; there were sand dunes here. In order to keep salt water entirely out of the Bolsa Chica estuary and wetlands, and to lower and control the level of the water in what was to become a lagoon, a dam with tide gates and a spillway was constructed near the entrance. [Photos taken in 1903 of Bolsa Dam, the automatic tide gates, and sand dunes are in the Water Resources Center Archives at UCB, and reproduced in Wiegel (2004).] The dam was made for a duck-hunting club's diked ponds (Schuyler, et al., 1900; Schuyler, 1903; 1904; Flaccus, 2006). This was to exclude ocean water from most of the estuary. After the dam was built, the remaining tidal prism (seaward of the dam) was so small that the entrance to the ocean closed. A channel, about 500 feet long, was dug in the hardpan between the Bolsa Chica Mesa and the sand spit, to connect this "outer bay" (Outer Bolsa Bay) with Anaheim Bay. Then, the tidal flows were via Anaheim Bay's sloughs and its ocean entrance. Schuyler et al. (1900, p. 6) remarked that reliable witnesses had observed in the years prior to the construction of the dam and tide gates, that the entrance closed naturally on occasions, and reopened after accumulation of water in the estuary. The location of Bolsa Creek, sand dunes, the dam, Bolsa Inlet, and the canal are on a map in Schuyler (1900). [**Note.** Huntington Harbour, a large residential marina, was constructed many decades later, in the southeast end of Anaheim Bay. It was completed in 1982, about 20 years after it was started (e.g., Nichol, Crumpley, and Byrnes, 1989; Wiegel, 2004).]

Development of the Huntington Beach Oil Field started in 1920, with many wells in the Bolsa Chica wetlands and in nearby oil fields; and later, an under-ocean field. Slant drilling was used (whipstocks to deflect the holes) under the highway and nearshore in the Huntington Beach New Offshore Field, the Tideland Pool, starting in 1938 (Barnes, 1945). Subsidence of several feet occurred, on land and offshore; Two maps showing the amount of ground subsidence in the Bolsa Chica area are in Gravens (1990), reproduced from a report by Woodward Clyde Consultants (1984). They are for the intervals 1933-1972, and 1964-1969. Gravens said "...The major subsidence area has coincided with the limits of the Huntington Beach oil field...Estimates of the maximum amount of subsidence have ranged up to 5 ft since 1920 when oil production began...The maximum range of subsidence from 1955 to 1968 was reported as 0.15 ft (1.8 in.) per year, but this rate decreased to 0.05 ft (0.6 in.) per year from 1968 to 1972...the decrease ...attributed to water injection of oil producing zones which was initiated in 1959."

When the end of the economic life of the oil field was approaching, plans were made for the development of the property. The plans included a marina and an ocean entrance. This was not done. In 1973 several hundred acres were conveyed to the State of California; it became the Bolsa Chica Ecological Reserve. Subsequently, several alternative conceptual plans were developed and studies made in regard to the remaining portion of the lowlands. For details of the plans, see Chambers Group, Inc. (2000; 2001), Moffatt & Nichol (2002), and California Coastal Commission (2001/2002). An environmental impact report and statement was prepared for restoration of the wetlands/ lowlands; the *Bolsa Chica Lowlands Restoration Project*. A consistency determination was made by the California Coastal Commission in 2001-2002. The concept plan was adopted, and implemented. This was without flood diversion into the project, and with construction of a non-navigable ocean inlet with jetties, and a highway bridge over the inlet. It includes two tidal basins; the large Full Tidal Basin, a smaller Muted Tidal Basin which is mostly marshlands, an area left unchanged as seasonal pond habitats, and an area "reserved for the future." The muted tidal area was connected to the full tidal basin by culverts through levees; the area experiences regular tidal ebb and flow, but not the full range of the tides. The Full Tidal Basin was connected to the ocean by a nonnavigable inlet with stone jetties, near the southern boundary of the project. The entrance was dredged through the beach. An "...ebb-tide bar was 'pre-filled' with sandy material dredged from the full tidal basin." A 4-lane highway bridge (Pacific Coast Highway) was constructed over this inlet, with a pedestrian crossing and bicycle lanes, separated from the vehicle lanes (California Coastal Commission, 2001/2002). It was expected that a flood-tide bar would form inside the entrance, which would require dredging. This occurred, and the first dredging was done in January-April 2009; and the 180,000 cu. m. of sand dredged were placed on the adjacent beach (Boudreau, 2009). The dredging schedule and placement of the material on the beach had to accommodate the California grunion (Leuresthes tenius) spawning activity. The East Garden Grove/ Winterberg flood control channel does not discharge into this restoration project. Rather, it remains connected, with a tide gate, to Outer Bolsa Bay, the canal, Huntington Harbour, Anaheim Bay and its ocean entrance. Bolsa Chica State Beach may have a "hotspot," or perhaps just a shoreline undulation, in the vicinity of the location of the pre-1899 tidal entrance to the estuary (Wiegel, 2004).

Bolsa Chica State Beach is heavily used, for multiple uses. Surfers are one of the biggest user groups of this 3-mile long reach. Part of the study for the restoration project was to obtain information about the effects/ impacts of a non-navigable tidal inlet on beach and surf recreation. A study was made by Thomas Pratte (1991) for Moffatt & Nichol, Engineers, to "...define uses and characteristics of surf sites such that the tidal inlet structures and channel can be designed to avoid or mitigate adverse impacts on the surfing resources." The study was comprised of surveys of surfers, wave observations, lifeguard interviews, and research about impacts of jetty structures on surfing. A detailed questionnaire (9 questions, and a section at the end for comments) was used to help determine user profiles of surfers. The surfers surveyed were told of the reason for the survey; and 29 of the 50 questionnaires distributed were returned. One of the findings was that this reach of shore and breaker zone was the favorite place to surf in Orange County. The surfing use pattern was presented in the report.

As mentioned previously, major changes, both natural and anthropogenic, have affected the supply and distribution of beach sand. However, owing to beach nourishment at Surfside-Sunset in recent decades, and the alongshore transport of sand, the beach to the southeast which includes Bolsa Chica State Beach, has become wider. Damage that occurred at the Bolsa Chica State Beach during the severe wave event of 16-18 Jan. 1988 has been described in a previous section.

Tsunamis

The California coast is subject to tsunamis (e.g., Houston, 1980; Lander, Lockridge and Kozuch, 1993; Synolakis, McCarthy, et al., 1998; California Governor's Office of Emergency Services, 1997; California Seismic Safety Commission, 2005). Major tsunamis from far-field sources (tele-tsunamis) have been: 11 Nov. 1922 (source, Chile); 1 April 1946 (source, Aleutian Trench); 23 May 1960 (source, Chile), and 28 March 1964 (source, Alaska). Damage to the Los Angeles Port and the Long Beach Port by the 23 May 1960 and 28 March 1964 tsunamis were mentioned by William Herron (USACE, Los Angeles District, 1986, p. 6-60). He described the strong seiching action in portions of the harbor (e.g., the Cerritos Channel), and resulting damage during the 23 May 1960 tsunami. He also commented on the 28 March 1964 tsunami, and said that "the seiching was much lower and all of the ancient and weakened piling systems had been destroyed by the earlier (sic tsunami) and replaced with new construction, so that damage was minor." Wilson (1971) reproduced copies of marigrams from one or more locations in the Los Angeles/Long Beach Harbors for the four tsunamis listed above. Plots are given of wave energy spectra he calculated numerically from the marigrams. The values of spectral peaks are close to his calculations of resonant or near-resonant modes of oscillation of the shelf off San Pedro Bay. More details are in the section *Seiching; Harbor Surging* herein. [For additional spectral studies of tsunami induced oscillations (the 1960 and 1964 events) in Long Angeles/Long Beach Harbors, and San Pedro Bay, see Raichlen, 1971; 1972.]

Probability predictions of tsunamis from far-field sources (tele-tsunamis) are in three reports prepared for the Federal Insurance Administration (FIA) by the U.S. Army Corps of Engineers, Waterways Experiment Station; two by Houston and Garcia (1974; 1978) and one by Houston (1980). Predicted 100-year and 500-year elevations ("runups") are shown on a series of plates (from U.S. Geological Survey Topographic Maps); 11 of which are between San Pedro and the Newport Bay entrance. Values of the 100-year runup ranged from 4.7 to 7.0 feet, with most being from 6.1 and 7.0 feet. Values of the 500-year runup ranged from 7.6 to 11.4 feet, with most being from 10.5 to 11.4 feet. Houston and Garcia say (1974, p. xi, Preface; Instructive Addendum):

"A 100-year runup is one that is equaled or exceeded with an average frequency of once every 100 years;
a 500-year runup has a corresponding definition."
"Runup values in this report are referenced to local mean sea level (msl) datum.
"The combined effects of astronomical tides and tsunamis are incorporated into the analysis as well as local response effects where judged significant."
"The primary area of inundation is interpreted as being that which lies between the shoreline and a local contour of elevation numerically equal to the runup value."
"No attempt has been made in this study to include the effects of storm surge and wind-generated waves in the computation of the runup values."

[**Notes. 1)** Synolakis, McCarthy, Titov, and Borrero (1997, p. 1,229) made the following comment: "The computational boundary was a vertical wall at the shoreline, i.e., there were no inundation computations. Houston (1980) noted that the runup elevations, i.e., the elevation of the maximum inland penetration of the tsunamis may not equal shoreline elevations at locations where dunes prevent flooding, of if the land is flat, where inland flooding may be extensive." **2)** Run-up and inundation calculations could be made using appropriate numerical models described in several of the papers in *Tsunamis* (Bernard and Robinson, eds., 2008).]

Borrero, Cho, Moore II, Richardson and Synolakis (2005), and Synolakis, Moore II, Borrero and Richardson (2005) wrote about several possible locally generated tsunamis in southern California; caused by relatively high speed submarine landslides. The authors discussed how a locally generated tsunami might adversely affect the ports of Long Beach and Los Angeles. Owing partly to this, the author prepared a list of nearly 350 references about tsunamis generated by rapid mass movements either submerged or from land into the ocean, or into a bay, lake, or reservoir (Wiegel, 2008). The list is available in print and electronic format at the Univ. California Water Resources Center Archives, Berkeley, CA (http://www.lib.berkeley.edu/WRCA/tsunamis.html) It is also available in electronic format as part of the international journal of the Tsunami Society; *Science of Tsunami Hazards* (http//www.sthjournal.org/sth6.htm).

The large Palos Verdes debris avalanche (slide), of "hummocky blocky topography" originated from the Palos Verdes Slope, and is seaward of the San Pedro Sea Valley (Gorsline, Kolpack et al., 1984; Bohannon and Gardner, 2004; Normark, McGann, Sliter, 2004; Locat, Lee, Locat, and Imran, 2004). It occurred about 7,500 BP, based on carbon-14 dating of foraminifera in cores (Normark, McGann and Sliter, 2004). They estimated the volume of the avalanche to be a maximum of about 0.8 cubic km. It may have generated a tsunami; and quite likely did so according to Locat, Lee, et al. (2004). They used numerical models to estimate the avalanche speed and deformation versus time; and resulting tsunami. The slide was probably triggered by a major earthquake (Normark, et al., 2004). One of the problems associated with studying this event of so long ago, is that "paleo-sediment" studies of tsunami runup and inundation are likely impossible. The mean sea level elevation at 7500 BP was probably about 40 feet lower than today's (e.g., Shepard, 1964); the inundated region is covered by sea water.

Questions - Would there have been tsunamis generated by two mechanisms nearly simultaneously - one by a tectonic displacement and another by an underwater slide triggered by the earthquake? Also, the tsunami probabilities in Houston and Garcia were for tele-tsunamis generated by underwater tectonic displacements. The hypothesized event for a local tsunami generated by a submarine landslide (avalanche) such as the Palos Verdes Debris avalanche is for a different "population". These are two different tsunami "populations." How should two different populations be treated in estimating the probability of occurrence?

Studies were made by Moffatt & Nichol, Engineers (2007) about the likelihood (the probability) of tsunamis being generated locally, and their effects in the Ports of Long Beach and Los Angeles; and also one hypothesized distant-source. A review was made of historical tsunamis that impacted the two ports; these were from distant sources, Chile and Alaska. Scenarios were developed, and numerical (hydrodynamical) models used to generate and propagate hypothetical tsunamis from these sources to, and into the ports. Seven potential tsunami sources were modelled; four local tectonic scenarios, two local submarine-landslide scenarios, and one distant-source scenario (Cascadia Subduction Zone). Potential impacts to the ports from the scenario tsunamis were described. The authors say (pp 1-2):

"The study expands on the previous work in that it includes more details regarding local maximum water levels, current speeds, arrival times, and overtopping rates at selected locations. ...the likelihood of the occurrence of these potential sources is also discussed to place the results in the proper perspective for the design of coastal structures."

One of their conclusions (p. 84) was: "...Based on the seismicity, geodetics and geology, a large locally generated tsunami from either local seismic activity or a local submarine landslide would likely not occur more than once every 10,000 years."

The following publication is useful when planning for tsunami mitigation: *Designing for Tsunamis: Seven Principals for Planning and Designing for Tsunamis*, prepared by the U.S. National Tsunami Hazards Mitigation Program (NTHMP - NOAA, USGS, FEMA, NSF, Alaska, California, Hawaii, Oregon, Washington (NTHMP, 2001). For additional background, including numerical modeling of tsunami generation, travel, run-up, and inundation, see *Tsunamis* (Bernard and Robinson, eds., 2009).

Long Beach Earthquake of 10 March 1933; Newport-Inglewood Fault Zone; Effects in Vicinity of Bolsa Chica

The Newport-Inglewood fault zone is oriented northwest-southeast, as is the shoreline in the Bolsa Chica and contiguous region. According to Barrows (1974), Bolsa Chica Mesa is separated into two parts, about 3,000 feet inland from the shoreline; a "surface expression of the single major fault of the Newport-Inglewood structural zone that reaches the surface of Bolsa Chica Mesa." The fault zone "tends" offshore at Newport Bay. What is known as the Long Beach Earthquake (owing to the loss of life, many injuries, and great damage in Long Beach) occurred on 10 March 1933, magnitude 6.3 on the Richter scale. Its epicenter has usually been given as about 3-1/2 miles (5 to 6 km) offshore Newport Beach, near the Newport Submarine Canyon (e.g., Barrows, 1974). However, a reanalysis by Hauksson and Gross (1991) of seismic data using modern techniques, and other information, have led to relocating the foreshock/ main shock/ aftershock sequence. They concluded that "...the rupture initiated near the Huntington Beach - Newport Beach City boundary and extended unilaterally to the northwest to a distance of 13 to 16 km." It was "an almost pure strike-slip." They concluded the "main shock hypocenter" was onshore, rather than offshore. Settling cracks caused by the earthquake, at the shoulder of Pacific Coast Highway, can be seen in a photo reproduced in Barrows. Major slumping and cracks occurred in the "causeway" across Bolsa Chica Bay to the Bolsa Chica Gun Club, which can be seen in other photos. [Barrows included many photos, from the Long Beach Public Library and other sources.] [**Note.** No tsunami was observed to have occurred (Barrows, 1974, pp. 85, 89).]

Historical Notes

1) The first conference on coastal engineering was held in the auditorium (named Rainbow Pier, although not a pier, and which no longer exists) on a fill, and protected by a breakwater at the ocean's edge in Long Beach, California, in October 1950. It was organized by Morrough P. O'Brien and J.W. Johnson. Its purpose was to make available to practicing engineers and scientists the state of the art and science related to the design and planning of coastal works. It was organized by the University of California Engineering Extension. Each presentation was by invitation; written versions are in the proceedings, edited by J.W. Johnson, and published by the Council on Wave Research of The Engineering Foundation. This was followed by three other conferences in the USA, one at the Gulf Coast, one on the East Coast, and one at the Great Lakes. Starting with the 5th, held in Grenoble, France, they became known as the international conferences on coastal engineering (ICCE) (e.g., Wiegel and Saville, Jr., 1996).

2) One of the earliest uses of a wave refraction diagram was for a portion of San Pedro Bay, as part of a hydraulic model study (M.S. thesis) of the manmade Cabrillo Beach at the base of the San Pedro Breakwater, by Herbert C. Gee, a U.S. Army Corps of Engineer officer while a graduate student at the University of California. It was done under the supervision of Professor Morrough P. O'Brien; see Gee (1938), and Dunham (1986, p. 6-48). At a later date, O'Brien (1946; 1950) and Horrer (1950) used refraction diagrams in their studies of wave damage that had occurred to the Long Beach (Harbor) Breakwater in 1930, and wave damage in 1939 to the Middle Breakwater. Extensive use was made of refraction diagrams by the Corps' for San Pedro Bay; these are in the March 1962 report by USACE, Los Angeles District (also see Dunham, 1951).]

3) A widely used formula for the relationship between the alongshore component of wave energy and the littoral transport of sand along a beach was developed at the USACE, Los Angeles District as part of studies of San Pedro Bay and Santa Monica Bay beaches (e.g., Eaton, 1951; Wiegel and Saville, Jr., 1996, p. 529). This formula was based on the "average work factor" presented in a Scripps Institution of Oceanography (SIO, 1947) report to the USACE, Los Angeles Office. In this report is the statement (p. 18): "...in the transport of sand by wave action it appears that wave work rather than wave height is the significant parameter." An equation for the time rate of work (wave power) was developed in terms of significant wave height, associated significant wave period, and the frequency distribution of these terms in the summation H^2Ts per unit length of beach (pp 18-22). This formula is commonly known as the SPM formula (*Shore Protection Manual*). An early use of the SPM formula was for the beach beginning at the Anaheim Bay south jetty (Caldwell, 1956). Local data were used to obtain the forcings, and the empirical correlation coefficient in the equation. The data were: collection and sieve analysis of sand samples; seven sets of beach profiles surveyed along six ranges in the immediate area in 1948 and 1949; six sets of aerial photographs in 1948 and 1949; wave measurements by two gages on Huntington Pier; wave hindcasts using daily synoptic weather maps. For recent updates of this and similar formulae, see Kamphuis (1991; 1993); Schooness and Theron (1996).]

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References

Adams, P.N., D. L. Inman, and N.E. Graham, "Southern California Deep-water Wave Climate Characterization and Application to Coastal Procedures," *Jour. Coastal Research*, Vol. 4, No. 4, 2008, pp 1,022-1,035

Alan, J.C., and P.D. Komar, "Climatic Controls on U.S. West Coast Erosion Processes," *Jour. Coastal Research*, Vol. 22, 2006, pp 511-529

Allen, D.R., and M.N. Mayuga, "The Mechanisms of Compaction and Rebound, Wilmington Field, Long Beach, California, USA," in *Land Subsidence. Proceedings of the Tokyo Symposium, Sept. 1969*, Pub. jointly by IASH and UNESCO, 1970, pp 410-422

American Shore and Beach Preservation Association (ASBPA), "Honoring the Best Beaches," by Stephen Higgins, *Coastal Voice*, Jan. 2008, p. 8

Anon., "Fifth Time Around, As California Pier Reappears," *Civil Engineering*, Vol. 62, No. 7, July 1992, p. 12

Anon., "The Construction of Pier 400," *Civil Engineering*, Vol. 71, No. 12, Dec. 2001, pp 36-37

Armstrong, George, and Reinhard E. Flick, "Storm Damage Assessment for the January 1988 Storm Along the Southern California Shoreline," *Shore & Beach*, Vol. 57, No. 4, Oct. 1989, pp 18-23

Arthur, R.S., T.E. Saur, R. Anderson, W.V. Burt, and W. Thompson, *A Statistical Study of Wave Conditions at Five Open Sea Locations Along the California Coast*, Univ. of California, Scripps Institution of Oceanography, La Jolla, CA, for USACE, Los Angeles Office, Rept. No. 68, 1947, 34 pp

Arthur, R.S., "The Effect of Islands on Surface Waves," *Bulletin of the Scripps Institution of Oceanography*, Vol. 6, 1951, pp 1-26

ASCE, Coastal, Oceans, Ports, and Rivers Institute (COPRI), *Keynote: COPRI Update February 2009*, 3 pp, http://mail.google.com/mail/?ui=2&ik=522c5ael13&view=pt&searc..

Barnes, Kenneth Boyd, "Wells Slanted Out 3,700 Feet Tap Under-Ocean Pool," *Oil and Gas Journal*, Vol. 44, No. 26, Nov. 1945, pp 82-89

Barrows, Alan G., *A Review of the Geology and Earthquake History of the Newport-Inglewood Structural Zone, Southern California*, Division of Mines and Geology, The Resources Agency, State of California, Special Report 114, 1974, 12 pp

Beach California.com, *Photo of The Wedge - Newport Beach Famous Body Surfing Beach*, 2 - page printed 5/31/2009
http://www.beachcalifornia.com/newport-beach-wedge.html

Bernard, Eddie, and Allan R. Robinson, eds., *Tsunamis*, in

The Sea, Ideas and Observations on Progress in the Study of the Seas, Vol. 15, Harvard Univ. Press, 2008, 450 pp

Bohannon, R.G., and J.V. Gardner, "Submarine Landslides of San Pedro Sea Valley, Southwest Long Beach, California," *Marine Geology*, Vol 203, 2004, pp 261-268

Borrero, Jose, Sungbin Cho, James E. Moore II, Harry W. Richardson, and Costas Synolakis, "Could It Happen Here?," *Civil Engineering*, Vol. 75, No. 4, April 2005, pp 54-65

Boudreau, Russell H., (Moffatt & Nichol, Engineers, Long Beach, CA), *Telephone conversation with R.L. Wiegel*, 6 May 2009, 15, 24 June 2009; 11 Aug. 2009

Bromirski, Peter D., Reinhard E. Flick, Daniel R. Cayan, "Storminess Variability Along the California Coast: 1858-2000," *Journal of Climate*, Vol. 16, 2003, pp 982-992

Brownlie, William R., and Brent D. Taylor, *Sediment Management for Southern California Mountains, Coastal Plains, and Shorelines, Part C - Coastal Sediment Delivery by Major Rivers in Southern California*, Calif. Institute of Technology, Environmental Quality Laboratory, Pasadena, CA, Rept. No. 17-C, Feb. 1981, 314 pp

Bryant, Ryan, "The Lure of The Wedge, California's Freakish Wave," *The New York Times*, 9 June 2006, 3-page printout, 6/18/2009
http://travel.nytimes.com/2006/06/09/travel/09wedge.html

Caldwell, Joseph, M., *Wave Action and Sand Movement Near Anaheim Bay, California*, USACE, Beach Erosion Board, Tech. Memo. No. 68, Feb. 1956, 21 pp

California Coastal Commission, *Proposed Findings on Consistency Determination*, Consistency Determination No. CD-061-01, File Date 6/28/2001; Commission Vote 11/13/2001; Hearings on Findings 1/7/2002. Adopted. 61 pp, 23 exhibits, 4 appendices

California, Governor's Office of Emergency Services, *Findings & Recommendations for Mitigating the Risks of Tsunamis in California*, Sept. 1997, 30 pp

California Seismic Safety Commission, *The Tsunami Threat to California: Findings and Recommendations on Tsunami Hazards and Risks*, CSSC 05-03, Dec. 2005, 15 pp

Carr, John H., "Long-period Waves or Surges in Harbors," *Transactions, ASCE*, Vol. 118, 1953, pp 588-603. "Discussions," pp 604-615; "Closure," pp 615-616

Casey, Nicholas, "Los Angeles Port's Rivals Make Gains," *Wall Street Journal*, 14 April 2009, p. A4

Cayan, D.R., and R.E. Flick, *Extreme Sea Levels in San Diego, California, Winter 1982-1983*, SIO Reference Series No. 85-3, Scripps Institution of Oceanography, Univ. California, San Diego, Feb. 1985, 58 pp

Chambers Group, Inc., *Final EIR/EIS for the Bolsa Chica Lowlands Restoration Project. DRAFT*, 4 volumes prepared for the California State Lands Commission, U.S. Fish & Wildlife Service, and U.S. Army Corps of Engineers, July 2000, various pagination. The Final Report was issued on a CD ROM, April 2001

Cho, Adrian, "Economics Nobel: Laureates Analyzed Economics Outside Markets," *Science*, Vol. 326, 16 Oct. 2009, p. 347

Clancy, Robert M., Fred E. Camfield, and Christine Schneider, "Low-Cost Measurements of Shoreline Change," in *Proc. of Coastal Structures '83, March 9-11, 1983, Arlington, VA*, ASCE, 1983, pp 717-726

Coleman, J.M., and L.D. Wright, "Modern River Deltas: Variability of Processes and Sand Bodies," in *Deltas: Models for Exploration*, 2nd Edition, ed. M.L. Broussard, Houston Geological Soc., 1975, pp 99-150

Coleman, James M., *Deltas. Processes & Models of Deposition for Exploration*, Second Edition, International Human Resources Development Corp., Boston, 1982, 124 pp

Committee on Beach Nourishment and Protection (R.J. Seymour, Chair, N.E. Bockstael, T.J. Campbell, R.G. Dean, P.D. Komar, O.H. Pilkey, A.P. Pratt, M.R. Snow, R.F. Van Dolah, J.R. Weggel, R.L. Wiegel), *Beach Nourishment and Protection*, Marine Board, National Research Council, National Academy Press, Washington D.C. 1995, 334 pp

Dana, Richard Henry, *Two Years Before The Mast*, Grossett & Dunlop, Pub., New York, 1927, 418 pp

Davidson, George, as quoted in *Speech in the U.S. Senate by U.S. Senator Stephen White*, in 1896

Dean, Robert G., Renjie Chen, Albert E. Browder, "Full Scale Monitoring Study of a Submerged Breakwater, Palm Beach, Florida, USA," *Coastal Engineering*, Vol. 29, 1997, pp 291-315

Designing for Tsunamis; Seven Principals for Planning and Designing for Tsunami Hazards, prepared for the U.S. National Tsunami Hazard Mitigation Program (NTHMP - NOAA, USGS, FEMA, NSF, Alaska, California, Hawaii, Oregon, and Washington), March 2001, 60 pp

Domurat, George W., and Arthur T. Shak, "The Storm of 1988 -- Damage to Coastal Structures," *Shore & Beach*, Vol. 57, No. 4, Oct. 1989, pp 24-27

Dorr, Jean B., *A Story of Seal Beach*, City of Seal Beach, CA, 1st printing, 1976; 2nd printing 1985, 45 pp

Dunham, James W., "Refraction and Diffraction Diagrams," in *Proceedings of First Conference on Coastal Engineering, Long Beach, California, October 1950*, ed. J.W. Johnson, Council on Wave Research, The Engineering Foundation, 1951, pp 33-49

Dunham, James W., "Use of Long Groins as Artificial Headlands," *Coastal Engineering: Santa Barbara Specialty Conference, Oct. 1965*, ASCE, pp 755-761

Dunham, James W., Interview in *Oral History of Coastal Engineering Activities in Southern California, 1930-1981*, USACE, Los Angeles District, 1986, 254 pp

Eaton, Richard O., "Littoral Processes on Sandy Coasts," *Proc. 1st Conf. on Coastal Engineering, Long Beach, Calif., Oct. 1950*, ed. J.W. Johnson, Council on Wave Research, The Engineering Foundation, 1951, pp 140-154

Edwards, Brian D., and Kevin R. Evans, *Saltwater Intrusion in Los Angeles Area Coastal Aquifers - the Marine Connection*, U.S. Geological Survey, Fact Sheet 030-02, 2002
http://geopubs.wr.usgs.gov/fact-sheet/fs030-02

Emery, K.O., *The Sea Off Southern California*, John Wiley & Sons, Inc., 1960, 366 pp

Everts Coastal, *Coast of Newport Beach: Shoreline Behavior and Coastal Processes*, prepared for City of Newport Beach, Public Works Dept., CA, April 1996, 112 pp

Ewing, Lesley, "Coastal Megacities and Hazards: Challenges and Opportunities," *Shore & Beach*, Vol. 76, No. 4, Fall 2008, pp 36-41

Felex, David, *Origin and Recent History of Newport Submarine Canyon, California Continental Borderland*, Tech. Rept. of ONR, Dept. Geological Sciences, Univ. of Southern California, No. USC Geology 69-3, May 1969, various pagination.

Fisher, P.J., P.A. Kreutzer, L.R. Morrison, J. Rudat, E.J. Tickner, J.M. Webb. M.M. Woods, R.W. Berry, M.J. Henry, D.M. Yoyt, M. Young, *Quaternary Shelf Deposits (Sand and Gravel) of Southern California*, prepared for the California Dept. of Boating and Waterways, by Mesa Inc., Chatsworth, CA, 1982, 73 pp

Flaccus, Gillian, (Associated Press Writer), "Dam Broken to Restore Calif. Wetlands," *Yahoo! News*, 26 Aug. 2006, 1-page print-out

Flick, R.E., and D.C. Cayan, "Extreme Sea Levels on the Coast of California," *Proc. 19th Inter. Conf. Coastal Engineering, 1984,*, ed. Billy L. Edge, ASCE, 1985, pp 886-198

Flick, R.E., and A. Badan-Dangon, "Coastal Sea Levels During the January 1988 Storm Off the Californias," *Shore & Beach*, Vol. 57, No. 4, Oct. 1989, pp 28-31

Flick, Reinhard E., "The Myth and Reality of Southern California Beaches," *Shore & Beach*, Vol. 61, No. 3, July 1993, pp 3-13

Flick, R.E., "Comparison of California Tides, Storm Surges, and Mean Sea Level During the El Nino Winters of 1982-83 and 1993-98," *Shore & Beach*, Vol. 66, No. 3 , 1998, pp 7-17

Flick, Reinhard E., Joseph F. Murray, and Lesley C. Ewing, "Trends in United States Tidal Datum Statistics and Tide Range," *Jour. Waterway, Port, Coastal and Ocean Engineering*, ASCE, Vol. 120, No. 4, July/Aug. 2003, pp 155-164

Gadd, Peter E., Craig B. Leidersdorf, Greg Hearon, Arthur T. Shak, and Joe Ryan, "Use of 'Statistical' Depth of Closure to Resolve Historical Changes in Shoreline Volume, Huntington Beach Littoral Cell, CA, USA," in *Coastal Engineering 2006, San Diego, California, USA, 3-8 Sept. 2006, Proceedings of the 30th International Conference*, ed. Jane McKee Smith, World Scientific, 2007, Vol. 5, pp 5,302-5,311

Gee, Herbert Caran, *A Model Study of Cabrillo Beach, Los Angeles, California*, M.S. thesis, (Civil Engineering), Graduate Division, University of California, Berkeley, California, 1938, 54 pp, appendices, photographs

Gilluly, James, and U.S. Grant, "Subsidence in the Long Beach Harbor Area, California," *Bulletin of the Geological Society of America*, Vol. 60, March 1949, pp 461-529

Google Maps, *Cabrillo Beach, CA*, vertical aerial photo
http://maps.google.com/maps?hl=cabrillo%20beach%ca&rlz=

Gorsline, D.S., and D.J. Grant, Sediment Textural Patterns on San Pedro Shelf, California (1951-1971): Reworking and Transport by Waves and Currents, in *Shelf Sediment Transport: Process and Pattern*, eds. D.J.F. Swift, D.E. Duane and O.H. Pilkey, Dowden, Hutchinson and Ross, Inc., Stroudsburg, PA, 1972, pp 575-600, 16 figs. and 1 table

Gravens, Mark B., *Bolsa Bay, California, Proposed Ocean Entrance System Study. Report 2. Comprehensive Shoreline Response Computer Simulation, Bolsa Bay, California*, USACE, Waterways Experiment Station, Coastal Engineering Research Center, Vicksburg, MS, Misc. Paper CERC-89-17, April 1990, 159 pp and appendices

Gray, Pamela Lee, *Images of America. Newport Beach*, Arcadia Publishing, 2003, reprinted 2004, 128 pp

Greenwell, Captain William, in *Report of the Superintendent, U.S. Coast Survey, 1861*, U.S. Gov't. Printing Office, Washington, D.C.

Gumprecht, Blake, *The Los Angeles River, Its Life, Death, and Possible Rebirth*, The John Hopkins University Press, 1999, 369 pp

Habel, John S., *Shoreline Subsidence and Sand Loss*, State of California, Dept. of Navigation and Ocean Development, Nov. 1978, 4 pp and appendix

Hansen, Brett, "California Wetlands Receive Environmental Face-Lift," *Civil Engineering*, Vol. 75, No. 1, Jan. 2005, pp 22-23

Hauksson, Egill, and Susanna Gross, "Source Parameters of the 1933 Long Beach Earthquake," *Bull. Seismological Soc. America*, Vol. 81, No.1, Feb. 1991, pp 81-98

Herron, William J., "Artificial Beaches in Southern California," *Shore and Beach*, Vol. 48, No. 1, 1980, pp 3-12

Herron, William, Interview in *Oral History of Coastal Engineering Activities in Southern California, 1930-1981*, USACE, Los Angeles District, Jan. 1986, 254 pp (see Ch. 6)

Higgins, Stephen, "Honoring the Best Beaches. 2007 Top Restored Beaches Award," *Coastal Voice*, ASBPA, Jan. 2008, p. 8

Hillyer, Theodore M., *Shoreline Protection of Beach Erosion Control Study. Final Report: An Analysis of the U.S. Army Corps of Engineers Shore Protection Program*, USACE, IWR Report 96-PS-1, June 1996, various pagination, Appendix E-F

Horrer, Paul L., "Southern Hemisphere Swell and Waves from a Tropical Storm at Long Beach, California," *Bulletin of the Beach Erosion Board*, Vol. 4, No. 3, 1 July 1950, pp 1-18

Houston, James R., and Andrew Garcia, *Type 16 Flood Insurance Study: Tsunami Prediction for Pacific Coast Communities*, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS, Tech. Rept. H-74-3, May 1974, 10 pp, 79 figures, 1 table, and a 37 p. appendix

Houston, James R., *Los Angeles Harbor Numerical Analysis of Harbor Oscillations. Final Report*, Misc. Paper H-77-2, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS, Feb. 1977, 228 pp (29 pp and 198 plates)

Houston, James R., *Type 19 Flood Insurance Study for Southern California. Final Report*, USACE, Waterways Experiment Station, Vicksburg, MS, Tech. Rept. No. HL-80-18, Sept. 1980, 174 pp

Idriss, I.M., and John T. Waggoner, *Subsidence in the Bolsa Chica Project Area*, letter report from Woodward Clyde Consultants to Signal Bolsa Corporation (Attn. John Holm), 16 Oct. 1986, 5 pp and 8 figures

Inman, D.L., and P.M. Masters, "Status of Research on the Nearshore," *Shore & Beach*, Vol. 62, No. 3, July 1994, pp 11-20

Interstate Electronics Corp., *Final Report, Fluorescent Sand Tracer Study, Orange County, California*, report to USACE, Los Angeles District, IEC-Oceanics Rept. No. 445-2, March 1966

Jen, Yuan, "Wave Refraction Near San Pedro Bay, California," *Jour. Waterways and Harbors Division, Proc. ASCE*, Vol. 95, No. WW 3, Aug. 1969, pp 379-393

Johnson, J.W., editor, *Proceedings of First Conference on Coastal Engineering, Long Beach, California, October 1950*, Council on Wave Research, The Engineering Foundation, 1951, 334 pp

Jones, S.G., G. Buzzoni, J. Foxworthy, A. Menendez, and S. Shahrestani, "Twenty-First Century Terminal," *Civil Engineering*, Vol. 71, No. 12, Dec. 2001, pp 38-41

Kadib, Andrew L., *Evaluation of Sand Nourishment Performance Along the Huntington Littoral Cell, California (1934-1992). Draft Report*, USACE, Los Angeles District, CCSTWS-OC-Report 96-8, Sept. 1996, various pagination

Kamphuis, J. William, "Alongshore Sediment Transport Rate," *Jour. Waterway, Port, Coastal, and Ocean Engineering*, ASCE, Vol. 117, No. 6, Nov./Dec. 1991, pp 624-640; "Closure," by J.M. Kamphuis, Vol. 119, No. 3, May/June 1993, pp 346-349

Kenyon, Edgar C., Jr., "History of Ocean Outlets, Los Angeles County Flood Control District," in *Proc. First Conference on Coastal Engineering, Long Beach, California, October 1950*, ed. J.W. Johnson, Council on Wave Research, The Engineering Foundation, 1951, pp 277-282

King, Philip, and Douglas Symes, "Potential Loss in GNP and GSP from Failure to Maintain California's Beaches," *Shore & Beach*, Vol. 72, Winter 2004, pp 3-7

King, Philip, "Financing Beach Restoration in California," *Shore & Beach*, Vol. 76, No. 2, Spring 2008, pp 44-52

Knapp, R.T., and V.A. Vanoni, *Wave and Surge Study for the Naval Operating Base, Terminal Island, California*, Calif. Institute of Technology, Hydraulic Structures Lab., Pasadena, CA, 1945

Lander, James F., P. Lockridge, and M. Kozuch, *Tsunamis Affecting the West Coast of the United States, 1806-1992*, NOAA, National Geophysical Data Center, U.S. Dept. Commerce, Boulder, CO, Key to Geophysical Records Documentation No. 29, Dec. 1993, 242 pp of text, 36 illustrations, 12 tables, 130 marigrams

Larkey, Kenneth, Publisher, *Long Beach, California. A Pictorial View of the Beach The Way It Was*,, pub. by Kenneth Larkey, Long Beach, CA, First printing 1990, Second printing 1994, 84 pp

Lee, Ellen K., *Newport Bay. A Pioneer History*, Newport Bay Historical Society, CA, 1973, 114 pp

Lee, Jin-Jin, *Wave induced Oscillations in Harbors of Arbitrary Shape*, California Inst. Technology, Pasadena, CA, Keck Lab. of Hydraulics and Water Resources, Rept.

No KH-R-20, Dec. 1969, 266 pp; also same title, in *Jour. Fluid Mechanics*, Vol. 45, 1971, pp 375-393

Leidersdorf, Craig B., Kenneth E. Smith, and Ruh-Ming Li, "The Talbert Channel Ocean Outlet Project," in *Coastal Engineering Practice '92. Proc. of a Specialty Conference on the Planning, Design, Construction, and Performance of Coastal Engineering Projects, Long Beach, CA, March 9-11, 1992*, ed. Steven A. Hughes, ASCE, 1992, pp 745-761

Lillevang, Omar, Interview in *Oral History of Coastal Engineering Activities in Southern California, 1930-1981*, USACE, Los Angeles District, 1986

Limber, P., K.B. Patsch, and G.B. Griggs, "Coastal Sediment Budgets and the Littoral Cut-off Diameter: A Grain Size Threshold for Quantifying Active Sediment Inputs," *Jour. Coastal Research*, March 2008, Vol. 24, No. 2B, pp 122-133

Locat, Jacques, Homa J. Lee, Pascal Locat, and Jasim Imran, "Numerical Analysis of the Mobility of the Palos Verdes Debris Avalanche, California, and Its Implication for the Generation of Tsunamis," *Marine Geology*, Vol. 203, 2004, pp 269-289

Los Angeles County, Dept. of Beaches and Harbors, *Lost and Found: Beach Sand Renourishment in L.A. County*, A 28-1/2 minute video, 1992

Magoon, Orville T., S. Jeffress Williams, Linda K. Lent, James A. Richmond, Donald D. Treadwell, Scott L. Douglass, Billy L. Edge, Lesley C. Ewing, and Anthony P. Pratt, "Economic Impact of Anthropogenic Activities on Coastlines of the United States," in *Proc. 29th International Conf. on Coastal Engineering, Lisbon, Portugal, Sept. 2004*, ed. Jane McKee Smith, World Scientific Pub. Co., 2005, pp 3,022-3,055

Malnic, Eric, "Huge Waves Cause Wide Destruction. Scores Flee as 25-Foot Breakers Batter Coastline," *Los Angeles Times*, Jan. 19, 1988, pp 1, 3, and 21

Marine Advisers, *A Statistical Survey of Ocean Wave Characteristics in Southern California Waters*, Marine Advisers, Inc., La Jolla, CA, 1961, 30 pp

Marroquin, Art, "Beach Cleanup Clock Ticking," *Daily Breeze*, 25 July 2009, pp A1 and A16

McEwen, George F., "Destructive High Waves long the Southern California Coast in 1934," *Shore and Beach*, Vol. 3, No. 2, April 1935, pp 61-64

McQuat, H.W., "History of Los Angeles Harbor," *Proceedings of First Conference on Coastal Engineering, Long Beach, California, October 1950*, ed. J.W. Johnson, Council on Wave Research, The Engineering Foundation, 1951, pp 259-270

Memita, Tetsu, and Tetsuo Sakai, "Influence of Incident Wave Angle on Mach-stem Breaking," in *Asian and Pacific Coasts 2003. Proc. of the 2nd International Conf.*, eds. Y. Goda, W. Kioka, and K. Nakaoka, World Scientific, Singapore, 2004, pp 60-61 with complete paper on CD in envelope at back of the book

Memita, Tetsu, and Tetsuo Sakai, "Estimation of Mach-stem Breaker Height Along Structures," in *Proc. 29th Inter. Conf. Coastal Engineering, 2004*, ed. Jane McKee Smith, World Scientific, Vol. 1, 2005, pp 642-653

Mesa, Chuck, "Nearshore Berm Performance at Newport Beach, California, USA," in *Coastal Engineering 1996. Proc. of the Twenty-fifth Conference, Orlando, FL, Sept. 2-6, 1996*, ed. Billy L. Edge, ASCE, 1997, pp 4,636-4,663

Moffatt & Nichol, Engineers, *Preliminary Engineering Studies for Bolsa Chica Wetlands Restoration. Final Report*, prepared for California State Coastal Conservancy, Dec. 1999, M&N File: 4012, various pagination. This is also Vol. III - Engineering Studies DRAFT EIR/EIS for the Bolsa Chica Lowlands Restoration Project, by Chambers Group, Inc., July 2000

Moffatt & Nichol, Engineers, *Tsunami Hazard Assessment for the Port of Long Beach and the Port of Los Angeles. Final Report*, Moffatt & Nichol, Engineers, Long Beach, CA, M&N File: 4839-169, April 2007, 91 pp

Munk, W.H., and M.A. Traylor, "Refraction of Ocean Waves -- A Process of Linking Underwater Topography to Beach Erosion," *Jour. of Geology*, Vol. 55, No. 1, 1947, pp 1-26

Nathan, Robert A., "Beach Erosion Problems and Protection Measures in the City of Long Beach," in *Alternative Technologies in Beach Preservation. Proc. of the 7th National Conference on Beach Preservation Technology, Tampa, Florida, Feb. 9-11, 1994*, Florida Shore & Beach Preservation Assoc., June 1994, pp 158-173

National Science and Technology Council, Executive Office of the President of the United States, *Tsunami Risk Reduction for the United States: A Framework for Action*, A joint Report of the Subcommittee on Disaster Reduction and the United States Group on Earth Observations, Dec. 2005, 23 pp and 3 appendices

National Tsunami Hazard Mitigation Program (NTHMP - NOAA, USGS, FEMA, NSF, Alaska, California, Hawaii, Oregon, and Washington), *Designing for Tsunamis: Seven Principals for Planning and Designing for Tsunami Hazards*, prepared for the U.S. National Tsunami Hazard Mitigation Program, March 2001, 60 pp

Neel, Charles H., Captain, CEC, U.S. Navy, *Surface Subsidence and Remedial Measures of the Long Beach Naval Shipyard, Long Beach, California*, Long Beach Naval Shipyard Employees Association, Inc, CA, 1957, 90 pp

Nemac, W., "Deltas - Remarks on Terminology and Classification" in *Coarse-Grained Deltas*, eds. A. Colella and David B. Prior, Inter. Assoc. of Sedimentologists, Special Pub. No. 10, Blackwell Scientific Pub., 1990, pp 3-12

Nichol, John M., James M. Crumpley, and Donald R. Byrnes, *The Development of Huntington Harbour Large Scale Marina*, presented at International Marina Conference, Southampton, U.K., 26-28 Sept. 1989, manuscript, Moffatt & Nichol, Engineers, Long Beach, CA, 15 pp

NOAA, National Data Buoy Center, U.S. Dept. Commerce, *Wave Buoy Data*. http://www.ndbc.noaa.gov

NOAA, U.S. Dept. Commerce, *San Pedro Channel, California, United States, West Coast*, Chart No. 18746 (corrected through Aug. 07, 2007), 37th Ed., 1 sheet, scale 1:80,000

NOAA, U.S. Dept. Commerce, *Los Angeles and Long Beach Harbor, California*, Chart No. 18751, 45 Ed., Nov. 2007 (corrected through Nov. 03, 2007), 1 sheet, scale 1:12,000

NOAA/NOS, *2008 Tide Tables, Height and Low Water Prediction: Europe and West Coast of Africa, Including the Mediterranean Sea*, 204 pp, *2008 Tide Tables, Height and Low Water Predictions, Central and Western Pacific Ocean and Indian Ocean*, 466 pp, pub. by ProStar Publications, Annapolis, MD, 2007, 204 pp, approved by the U.S. Coast Guard

Noble Consultants, Inc., *Balboa & Newport Ocean Pier Rehabilitation, Newport Beach, CA*, Newport Beach, CA, 1998, 1 page

Normark, William R., Mary McGann, and Ray Sliter, "Age of Palos Verdes Submarine Debris Avalanche, Southern California," *Marine Geology*, Vol. 203, 2004, pp 247-259

O'Brien, Morrough P., "The Coast of California as a Beach Erosion Laboratory," *Shore and Beach*, Vol. 4, No. 3, July 1936, pp 74-79

O'Brien, Morrough P., "Equilibrium Flow Areas of Tidal Inlets on Sandy Coasts," in *Proc. Tenth Conf. on Coastal Engineering, Tokyo, Japan, Sept. 1966*, ed. J.W. Johnson, ASCE, 1967, pp 676-686

O'Brien, M.P., *Wave Refraction at Long Beach and Santa Barbara, California*, Univ. California, Berkeley, CA, Dept. Engineering, Fluid Mechanics Lab., Tech. Rept. HE-116-246, 14 May 1947, 14 pp. Also, with same title in *Bulletin of the Beach Erosion Board*, Dept. of the Army, Corps of Engineers, Vol. 4, No. 1, 1950, pp 1-11

O'Reilly, W.C., "Modelling of Storm Waves of January 17-18, 1988," *Shore & Beach*, Vol. 57, No. 4, Oct. 1989, pp 32-36

Orange County Planning Commission, *The Master Plan of Shoreline Development for Orange County*, Adopted by Board of Supervisors, Nov. 12, 1941, Orange County, California, July 1941, 83 pp

O'Reilly, W.C., and R.T. Guza, "A Comparison of Spectral Wave Models in the Southern California Bight," *Coastal Engineering*, Vol. 19, 1993, pp 263-282

O'Reilly, W.C., "The Southern California Wave Climate; Effects of Islands and Bathymetry," *Shore & Beach*, Vol. 61, No. 3, July 1993, pp 14-19 and cover

O'Reilly, W.C., and R.T. Guza, "Assimilating Coastal Wave Observations in Regional Swell Predictions. Part 1: Inverse Methods," *Jour. Physical Oceanography*, Vol. 28, No. 4, April 1998, pp 679-689

Ostrom, Elinor, *Public Entrepreneurship: A Case Study in Ground Water Basin Management*, Ph.D. thesis, Dept. of Political Science, Univ. of California, Los Angeles, University Microfilms, Inc., 65-5706, 1965, 606 pp

Patsch, K.B., and G.B. Griggs, *Development of Sand Budgets for California's Major Littoral Cells: Eureka, Santa Cruz, Southern Monterey Bay, Santa Barbara, Santa Monica, San Pedro, Laguna, Oceanside, Mission Bay, and Silver Strand Littoral Cells*, California Coastal Commission Sediment Management Work Group Report, California Dept. Boating and Waterways, 2005, 266 pp

Patterson, David R., "Beach Nourishment at Surfside-Sunset Beach, The Orange County Beach Erosion Project, Orange County, California," in *Beach Preservation Technology 88. Problems and Advancements in Beach Nourishment, March 23-25, 1988, Gainesville, FL. Proceedings*, Florida Shore & Beach Preservation Association, 1988, pp 47-58

Patterson, David R., and Donald T. Young, "Monitoring the Beach Nourishment Project at Surfside-Sunset Beach," in *Proc. Coastal Zone '89*, ed. Orville T. Magoon et al., ASCE, Vol. 2, pp 1,963-1,978

Patterson, R.L., and John A. Williamson, "Development of Newport Beach, California," *Shore & Beach*, Vol. 28, No. 1, April 1960, pp 22-25 and cover photo

Pawka, S.S. "Island Shadows in Wave Directional Spectra," *Jour. Geophys. Research*, Vol. 88, No. C4, 1983, pp 2,579-2,591

Pawka, S.S., D.L. Inman, and R.T. Guza, "Island Sheltering of Surface Gravity Waves: Model and Experiment," *Coastal Shelf Research*, Vol. 3, No. 1, 1984, pp 35-53

Pratte, Thomas P., *Recreational Beach Use and Surfing Assessment at Bolsa Chica State Beach*, prepared for The Koll Co., Newport Beach, CA, by Moffatt & Nichol, Engineers, M&N File 2778-09, June 1991, 4 appendices, 17 exhibits

Price, Reginald C., "Statement of the California Department of Water Resources," *Shore and Beach*, Vol. 34, No. 1, April 1966, pp 22-32

Proceedings of First Conference on Coastal Engineering, Long Beach, California, October 1950, ed. J.W. Johnson, Council on Wave Research, The Engineering Foundation, 1951, 334 pp

Quiroz, R.S., "The Climate of the 'El Nino' Winter of 1982-83: A Season of Extraordinary Climatic Anomalies," *Monthly Weather Review*, Vol. 111, No. 8, Aug. 1983, pp 1,685-1,706

Raichlen, Fredric, "Tsunamis: Some Laboratory and Field Observations," in *Proc. Twelfth Coastal Engineering Conference, Sept. 13-18, 1970, Washington, D.C.*, ed, J.W. Johnson, ASCE, 1971, Vol. 3, Ch. 127, pp 2,103-2,122

Raichlen, Fredric, "Discussion of 'Tsunami-Responses of San Pedro Bay and Shelf, Calif.," *Jour. Waterways, Harbors and Coastal Engineering Div., Proc. ASCE*, Vol 98, No. WW 1, Feb. 1972, pp 104-110

Ryan, Joseph B., (USACE, Los Angeles District), *Personal Communications: Memos and Fax's to R.L. Wiegel*, w/enc., 17, 23, and 26 Sept. 1993 and 22, 23 Nov. 1993; *Telephone Conversations*, 23, 24, and 28 Sept. 1993

Ryan, Joseph A, "Surfside-Sunset Beach Nourishment," *Fax to Prof. R.L. Wiegel*, from Ryan , USACE, Los Angeles District, 16 Dec. 2008, 2 pp

Ryan, Joseph A., *Photos of West Newport Beach Sand Backpassing (from Jon Moore of Noble Consulting), and Newport Beach Sand Backpassing Survey Control*, USACE, Los Angeles District, to R.L. Wiegel, 14 May 2009

Ryan, Joseph B., *Info. on Stage 12, Surfside-Sunset Work, Incl. Seal Beach and Anaheim Bay, and Google Photo of the Shore*, 20 May 2009, USACE, Los Angeles District. Also "Telephone Message 4 June 2009," in reply to R.L. Wiegel telephone message

Sahagun, Louis, "Long Beach's Barrier Riff," *Los Angeles Times*, 24 July 2009, p. A3

Schoonees, J.S. and A. K. Theron, "Improvement of the Most Accurate Longshore Transport Formula," in *Coastal Engineering 1996: Proc. of the Twenty-fifth International Conf., Sept. 2-6, 1996, Orlando, Florida, USA*, ed. Billy L. Edge, ASCE, 1997, Vol. 2, pp 3.65-3,665

Schuyler, Jas. D., et al., *Report of Board of Engineers on the Effect of the Construction of the Bolsa Chica Dam on the Drainage of the Adjacent Peatlands*, report to Bolsa Chica Gun Club (Attn. Attorney W.E. Dunn), March 16, 1900, 6 pp and map.

Schuyler, Jas. D., *Automatic Tide Gates*, (manuscript in UCB Water Resources Center Archives, Berkeley, CA), 21 Oct. 1903, 3 pp

Schuyler, Jas. D., "Automatic Tide Gates for the Bolsa Chica Gun Club, California," *Engineering News*, Vol. LI, No. 5, Feb. 1904, pp 114-115

Scripps Institution of Oceanography (SIO), *A Statistical Study of Wave Conditions at Five Open Sea Locations Along the California Coast*, prepared for U.S. Engineer Office, Los Angeles, Contract W-04-353-Eng-1951, by T. Saur, E.H. Anderson, W.V. Burt, and W. Thompson, with R.S. Arthur, H.U. Sverdrup and W.H. Munk as consultants, Univ. of California, July 1, 1947, 34 pp and appendices

Seymour, Richard J., R. Rae Strange III, Daniel R. Cayan, Robert A. Nathan, "Influence of El Ninos on California's Wave Climate," in *Nineteenth Coastal Engineering Conf., Proc. of the Inter. Conf., Sept. 3-7, 1984, Houston, Texas*, ed. Billy L. Edge, ASCE, 1985, Vol. 1, pp 577-592

Seymour, Richard J., "Editorial. The Great Storm of January 1988," *Shore & Beach*, Vol. 57, No. 4, Oct. 1989, p. 2 (a)

Seymour, Richard J., "Wave Observations in the Storm of 17-18 January 1988," *Shore & Beach*, Vol. 57, No. 4, Oct. 1989, pp 10-13 (b)

Seymour, R.J., D. Castel, D. McGehee, J. Thomas, and W. O'Reilly, "New Technology in Coastal Wave Monitoring,' in *Second International Symposium on Ocean Wave Measurement and Analysis," Waves '93*, ASCE, 1993, pp 105-123

Seymour, Richard J., "Wave Climate Variability in Southern California," *Jour. Waterway, Port, Coastal, and Ocean Engineering*, Vol. 122, No. 4, July/Aug. 1996, pp 182-186

Seymour, Richard J., "Effects of El Ninos on the West Coast Wave Climate," *Shore & Beach*, Vol. 66, No. 3, July 1998, pp 3-6

Seymour, Richard J., "Decadal Changes in Very Large Wave Occurrence on the US Pacific Coast," in *Proc. ICCE, Hamburg, Germany, 30 Aug.- 5 Sept. 2008, Hamburg, Germany*, 11 pp (in press),

Shak, A.T., and J.A. Ryan, "San Gabriel River to Newport Bay, Erosion Control Project, Orange County, California, 20 Years of Beach Replenishment," in *Coastal Engineering 1996. Proc. Twenty-fifth International Conf., Orlando, Florida, Sept. 2-6, 1996*, ed. Billy L. Edge, ASCE, 1997, pp 4,650-4,663

Shaw, Martha J., *Artificial Sediment Transport and Structures in Coastal Southern California*, Scripps Institution of Oceanography, Univ. California, San Diego, SIO Ref. No. 80-41, Dec. 1980, 109 pp

Shepard, Francis P., "Sea Level Changes in the Past 6000 Years: Possible Archaeological Significance," *Science*, Vol. 143, No. 3606, Feb. 7, 1964, pp 574-576

Shore Protection Manual, U.S. Army, Corps of Engineers, Waterways Experiment Station, Coastal Engineering Research Center, 4th Edition, Second Printing, U.S. Gov't.

Printing Office, Washington, D.C., 2 vols., various pagination

Snodgrass, F.E., G.W. Grove, K.F. Hasselmann, G.R. Miller, W.H. Munk, and W.H. Powers, "Propagation of Ocean Swell Across the Pacific," *Philosophical Trans., Royal Society of London*, Series A, Vol. 259, No. 1034, 1966, pp 431-497

Spano, John, "Time, Elements Take Toll on Southland Piers. 2 Have Been Shut; Repair on Others Limit Their Use," *Los Angeles Times*, 4 Dec. 1988, pp 14, 15, 18

Spencer, Donald G., "The Newport Beach Groin Field, Orange County, California," in *California's Battered Coast. Proc. from A Conference on Coastal Erosion, San Diego, Feb. 6-8, 1985*, ed., Jim McGrath, Conference Coordinator, California Coastal Commission, Sept. 1985, pp 151-201

Stanley, Daniel Jean, and Andrew G. Warne, "Worldwide Initiation of Holocene Marine Deltas by Deceleration of Sea-Level Rise," *Science*, Vol. 265, No. 5169, 8 July 1994, pp 228-231

Strange III, R.R., N.E. Graham, and D.R. Cayan, "Meteorological Development of the Unusually Severe Southern California Coastal Storm During January 16-18, 1988," *Shore & Beach*, Vol. 57, No. 4, Oct. 1989, pp 3-9

Strehle, R.W., "Subsidence in Long Beach," in *Geologic Field Guide to the Long Beach Area*, eds. D. Clarke and C. Henderson, Pac. Sec. Am. Assoc. of Petr. Geol., Los Angeles, CA, 1987, pp 69-79

Synolakis, C.E., D. McCarthy, V.V. Titov, and J. Borerro, "Evaluating the Tsunami Risk in California," in *California and the World Ocean '97. Conference Proceedings, March 24-27, 1997, San Diego, CA, U.S.A.*, eds. O.T. Magoon, H. Converse, B. Baird, and M. Miller-Henson, ASCE, 1998, pp 1,225-1,236

Synolakis, Costas E., James E. Moore II, Jose C. Borrero, and Harry W. Richardson, "Consequences Exaggerated?" in Letters/ Response, *Civil Engineering*, Vol. 75, No. 7, July 2005, pp 9-10

Talbert, T.B., *My Sixty Years in California*, Huntington Beach Press, 1952, 125 pp. Re-issued 1982, Ben Franklin Press, Huntington Beach, CA

Testa, Stephen M, "Elevation Changes Associated with Groundwater Withdrawal and Reinjection in the Wilmington Area, Los Angeles Coastal Plain, California," in *Land Subsidence: Proc. of the Fourth International Symposium on Land Subsidence, Houston, Texas, May 1991*, ed. A.I. Johnson, IAHS Publ. No. 200, 1992, pp 485-502

Thomas, J.O., D.D. McGehee, R.J. Seymour, and D. Castel, "Coastal Wave Data Dissemination Via the Internet," in *Proc. Third International Symposium on Ocean Wave Measurement and Analysis, Virginia Beach, VA, Nov. 3-7, 1997*, ASCE, 1997, Vol. 2, pp 1,380-1,390

Troxell, Harold C., and Others, *Floods of March 1938 in Southern California*, U.S. Geological Survey, Water-Supply Paper 844, 1942, 399 pp

Tsunamis, Eddie N. Bernard and Allan R. Robinson, eds., *The Sea, Ideas and Observations on Progress in the Study of the Seas*, Vol. 15, Harvard Univ. Press, 2009, 450 pp

USACE, IWR, *Shoreline Protection and Beach Erosion Control Study. Final Report: An Analysis of the U.S. Army Corps of Engineers Shore Protection Program*, by Theodore M. Hillyer, USACE, IWR Report 96-PS-1, June 1996, various pagination, Appendix E-F

USACE, Los Angeles District, *Beach-Erosion Control Report on Cooperative Study of Pacific Coast Line of the State of California, Point Mugu to San Pedro Breakwater*, by Colonel W.D., Luplow, Corps of Engineers, Sept. 1, 1950, 113 pp and 12 appendices

USACE, Los Angeles District, *Beach Erosion Control Report on Cooperative Study of Orange County, California, Appendix V, Phase 2*, March 1, 1962, various pagination, with appendices

USACE, Los Angeles District, *Special Study of City of Long Beach (Alamitos Bay), Beach Erosion Control Report on Coast of Southern California, Appendix VII*, Dec. 1966 (Revised 1967), 18 pp, 8 plates, 7 photos, 1 appendix

USACE, Los Angeles District, *Specifications for Restoration of San Pedro Breakwater at Los Angeles County, California*, DACW09-83-8-0040, July 1983

USACE, Los Angeles District, *Oral History of Coastal Engineering Activities in Southern California, 1930-1981*, Jan. 1986, 254 pp

USACE, Los Angeles District, *Interim Reconnaissance Report, Cabrillo Beach, Los Angeles, California*, Oct. 1989, 10 pp and plates

USACE, Los Angeles District, *Huntington Cliffs Reconnaissance Report, Huntington Beach, Orange County, California, Tech. Appendices (Coastal Engineering, Geotechnical, and Photographic Analysis)*, March 1993, 86 pp, 75 pp, and 13 figures

USACE, Los Angeles District, *Existing State of Orange County Coast. Final Report*, Coast of California Storm and Tidal Waves Study, South Coast Region, Orange County, April 1993, Rept. 93-1, various pagination

USACE, Los Angeles District, *Nearshore Hydrodynamical Factors and Wave Study of the Orange County Coast*, CCSTWS South Coast Region, Orange County, Final Report, No. 96-3, 1996, various pagination

USACE, Los Angeles District, *Evaluation of Sand*

Nourishment Performance Along the Huntington Littoral Cell (1934-1992). Draft Report, by Andrew L. Kadib, CCSTWS-OC-Report 96-8, Sept. 1996, various pagination

USACE , Los Angeles District, *Coast of California, Storm and Tidal Waves Study, South Coast Region, Orange County; Final Report*, U.S. Army Corps of Engineers (USACE), December 2002, various pagination

U.S. Coast & Geodetic Survey, *California. Las Bolsas Sheet, Topographic Map,* surveyed in 1894, edition of July 1896, reprinted Mar. 1900, 1 sheet

U.S. Coast Survey, *Report of the Superintendent of the Coast Survey Showing the Progress of the Survey During the Year 1861*, House of Representatives, 37th Congress, 2d Session, Government Printing Office, Washington D.C., 1862

U.S. Coast Survey, *Topography, New River to Bolsas Creek, Cal.*, Register No. 1345, surveyed in Feby., March, April 1873, 1 sheet

U.S. Congress, House of Representatives, *Beach Erosion Study, Orange County, Calif., Letter from The Secretary of War Transmitting A Letter from the Chief of Engineers, United States Army, Dated February 13, 1940, Submitting a Report*, Together with Accompanying Papers and Illustrations on a Beach Erosion Study, Orange County, Calif..., House of Representatives Document No. 637, Feb. 19, 1940, 27 pp, 19 illustrations

U.S. Congress, House of Representatives, *Anaheim Bay Harbor, Calif. Letter from The Secretary of The Army, Transmitting a Letter from the Chief of Engineers, United States Army, Dated Nov. 30, 1953, Submitting a Report*, Together with Accompanying Papers and an Illustration. on a Preliminary Examination and Survey of the Harbor at Anaheim Bay, Calif., with a View to Shore Protection, House Document No. 349, March 10, 1954, U.S. Gov't Printing Office, Wash. D.C., 43 pp and 1 illustration

U.S. Congress, House of Representatives, *San Gabriel River to Newport Bay, Orange County, California, Appendix V, Phase II, Beach Erosion Control Study, Letter from The Secretary of the Army Transmitting a Letter from the Chief of Engineers, Department of the Army, Dated August 8, 1962, Submitting a Report*, Together with Accompanying Papers and Illustrations on a Cooperative Beach Erosion Control Study of the Shore from San Gabriel River to Newport Bay, Orange County, California, Appendix V, Phase II,..., 87th Congress, 2d Session, House Document No. 602, Oct. 2, 1962, 158 pp

U.S. Congress, Senate Committee on Commerce, *Newport Bay, Calif., Letter from the Chief of Engineers, United States Army to the Chairman of the Committee on Commerce, Transmitting a Report on Newport Bay, Calif.*, Nov., 17, 1936, 75th Congress, 1st Session, U.S. Gov't. Printing Office, Washington, D.C., 1937, 17 pp, 1 folded map

U.S. Fish & Wildlife Service, Carlsbad Fish and Wildlife Office, "Southern California's Largest Wetland Restoration Project Set to Begin," *News Release*, U.S. Dept. Interior, 1 Sept. 2004, 4-page printout
http://carlsbad.fws.gov, or http://bolsachica.fws.gov

U.S. Fish & Wildlife Service, U.S. Dept. Interior, *Bolsa Chica Lowlands Restoration Project Solicitation 10114R004*, posted on website on 17 Jan. 2004
http:www.2.eps.gov/spg/))I/FWS/CGSWO/101814/synopsisP/html

U.S. Geological Survey, *Topographic Map, Southern California*, surveyed 1893-1900, original printing 1901, reprinted in 1921, 1 sheet

Vanoni, Vito, and John H. Carr, "Harbor Surging," in *Proceedings of First Conference on Coastal Engineering, Long Beach, California, October 1950*, ed. J.W. Johnson, Council on Wave Research, The Engineering Foundation, 1951, pp 60-68

Walker, James R., Robert A. Nathan, Richard J. Seymour, and R. Rea Strange III, "Coastal Design Criteria in Southern California," in *Nineteenth Coastal Engineering Conference. Proc. of the International Conf., Sept. 3-7, 1984, Houston, Texas*, ed. Billy L. Edge, ASCE, Vol. III, 1985, pp 2,827-2,841

Walker, James R., and Susan M. Brodeur, "The California Beach Nourishment Success Story," in *The State of the Art of Beach Nourishment. Proceedings of the 1993 National Conference on Beach Preservation Technology, 10-12 Feb. 1993, St. Petersburg, FL*, Florida Shore and Beach Preservation Assoc., compiled by Lawrence S. Tait, 1993, pp 239-258

Ware, Rick, "Eelgrass (Zostera marina) In Southern California Bays and Wetlands With Emphasis on Orange County, California," *Shore & Beach*, Vol. 61, No. 3, July 1993, pp 20-30

Water Replenishment District of Southern California, *Engineering Report Survey and Report (ESR) for 2008*, updated May 2, 2008, various pagination

Wells, J.T., and J.M. Coleman, "Deltaic Morphology and Sedimentology, with Special Reference to the Indus River Delta," in *Marine Geology and Oceanography of Arabian Sea and Coastal Pakistan*, eds. Bilal U. Haq and John D. Milliman, Van Nostrand Reinhold Co., 1984, Ch. 7, pp 86-100

White, Stephen M., *Deep Sea Harbor, San Pedro - Santa Monica*, Speech of Hon. Stephen M. White of California in the Senate of the United States, May 8, 9, and 12, 1896, U.S. Senate, 1896, 61 pp

Wiegel, R.L., and H.L. Kimberley, "Southern Swell Observed at Oceanside, California," *Trans. Amer. Geophys. Union*, Vol. 31, No. 5, Oct. 1950, pp 717-722

Wiegel, Robert L., "Water Wave Equivalent of Mach-Reflection" in *Proc. of Ninth Conference on Coastal Engineering, Lisbon, Portugal, June 1964*, ed. J.W. Johnson, ASCE, 1964, pp 82-102

Wiegel, Robert L., *Oceanographical Engineering*, Prentice-Hall, Inc., 1964, 532 pp

Wiegel, Robert L., "Ocean Beach Nourishment on the USA Pacific Coast," *Shore & Beach*, Vol. 62, No. 1, Jan. 1994, pp 11-36

Wiegel, Robert L., *Final Letter Report on Coast of California Storm and Tidal Waves Study, South Coast Region, Orange County*, prepared for USACE, Los Angeles District, 14 Nov. 1996, 33 pp

Wiegel, Robert L., *Technical Review of the April 2002 DRAFT Report Coast of California Storm and Tidal Waves Report, South Coast Region, Orange County, Excepting Chapters 1 and 8*, Letter reports to Tom Rossmiller, Public Facilities and Resources Dept., Orange County, 1st Rept., 7 June 2002, 50 pp; 2nd report, 12 June 2002, 17 pp

Wiegel, Robert L., and Thorndike Saville, Jr., "History of Coastal Engineering in the USA," in *History and Heritage of Coastal Engineering*, ed. Nicholas C. Kraus, ASCE, 1996, pp 513-600

Wiegel, Robert L., *Bolsa Chica Estuary/ Bay and Beach, Orange County, California; A Bit of History*, Univ. California, Berkeley, CA, Hydraulic Engineering Laboratory, Tech. Rept. UCB/HEL-2004-1, 34 pp, 1 appendix

Wiegel, Robert L., *Tsunami Information Sources, Part 4. (With a Section on Impulsively Generated Waves by a Rapid Mass Movement, Either Submerged, or Into a Body of Water)*, Univ. California, Dept. Civil & Environmental Engineering, Hydraulic Engineering Laboratory, Rept. UCB/HEL 2008-1), 14 March 2008, 64 pp. At
http://www.lib.berkeley.edu/WRCA/tsunamis.html
Also in the Tsunami Society International Journal *Science of Tsunami Hazards*, Vol. 28, No. 4 (Special Issue), 2009, pp 255-346
http://tsunamisociety.org/OnlineJournal09.html

Wikipedia, *Alameda Corridor*, 2-page printout on 12/24/2008
http://wikipedia.org/wiki/Alameda_Corridor

Wikipedia, *San Pedro, Los Angeles, California*, 16-page printout on 12/27/2008
http://en.wikipedia.org/wiki/San_Pedro,_Los_Angeles,_California

Wilson, Basil W., "Tsunami-Responses of San Pedro Bay and Shelf, Calif.," *Jour. Waterways, Harbors, and Coastal Engineering Div., Proc. ASCE*, Vol. 97, No. WW 2, May 1971, pp 239-258

Woodward Clyde Consultants, *Preliminary Evaluation of Ground Subsidence, Bolsa Chica Local Coastal Program, Bolsa Chica Planning Unit, Orange County, California*, Santa Ana, CA, prepared for Signal Landmark, Inc., Irvine, CA, 1984

Woodward Clyde Consultants, *Subsidence in the Bolsa Chica Project Area*, letter report to Signal Bolsa Corporation (Attn. Jeff Holm) from I.M. Idriss and John T. Waggoner, 16 Oct. 1986, 5 pp and 8 figures

Zetler, B.D., and R.E. Flick, "Predicted Extreme High Tides for Mixed-tide Regime," Jour. Physical Oceanography, Vol. 15, No. 3, March 1985,pp 357-359

Zetler, Bernard D., and Reinhard E. Flick, "Predicted Extreme High Tides for California: 1983-2000," *Jour. of Waterway, Port, Coastal and Ocean Engineering*, ASCE, Vol. 111, No. 4, July 1985, pp 758-765

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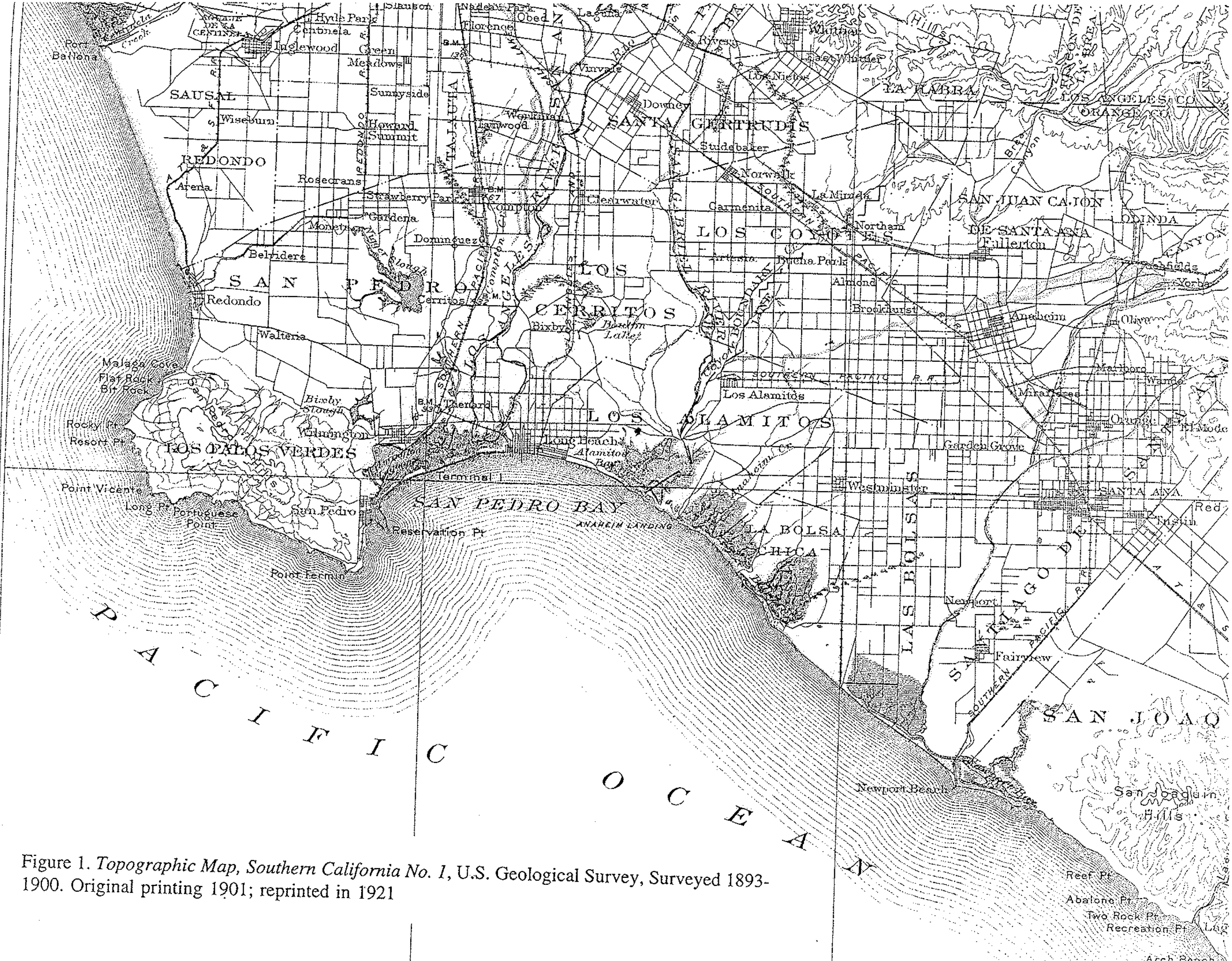

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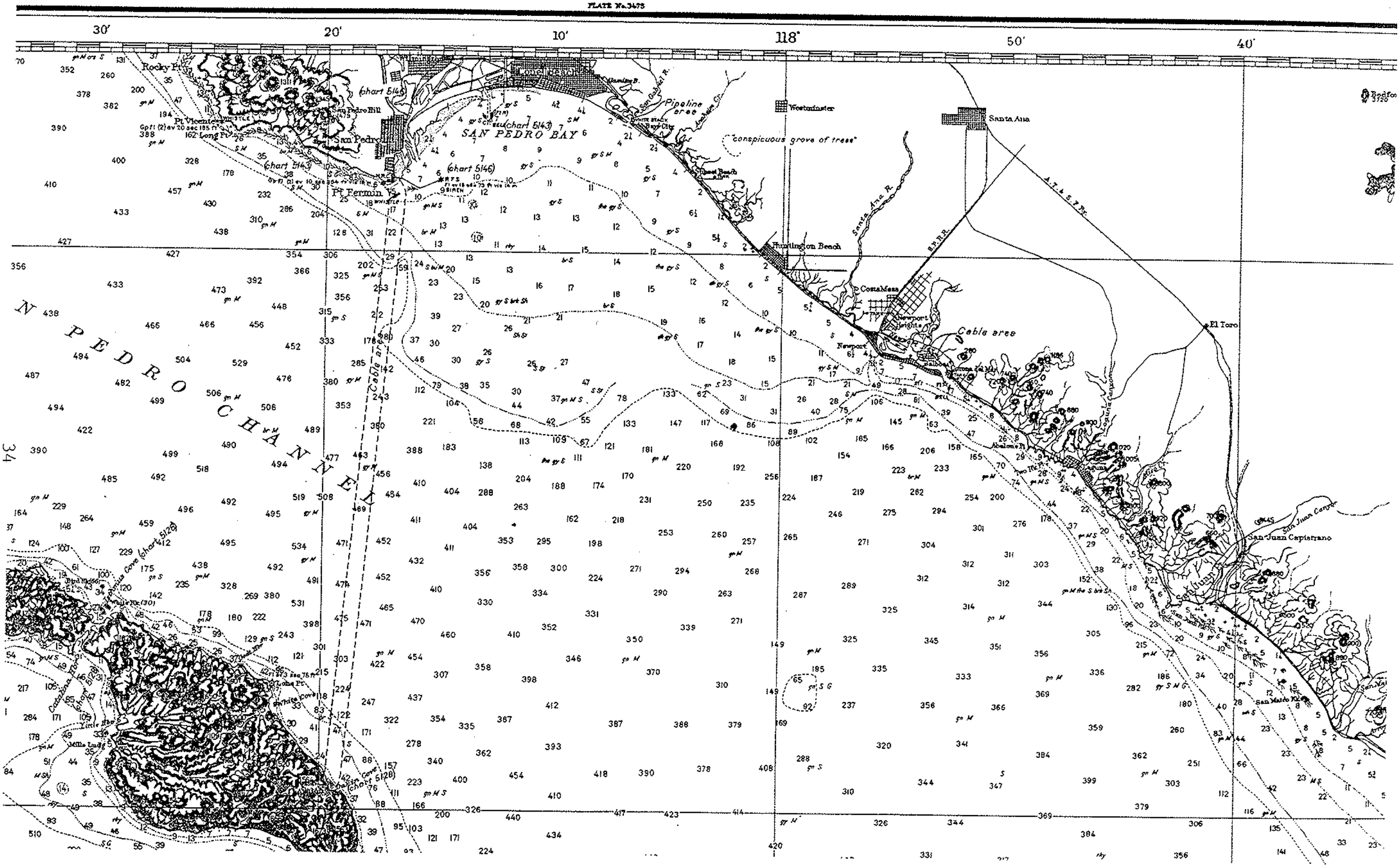

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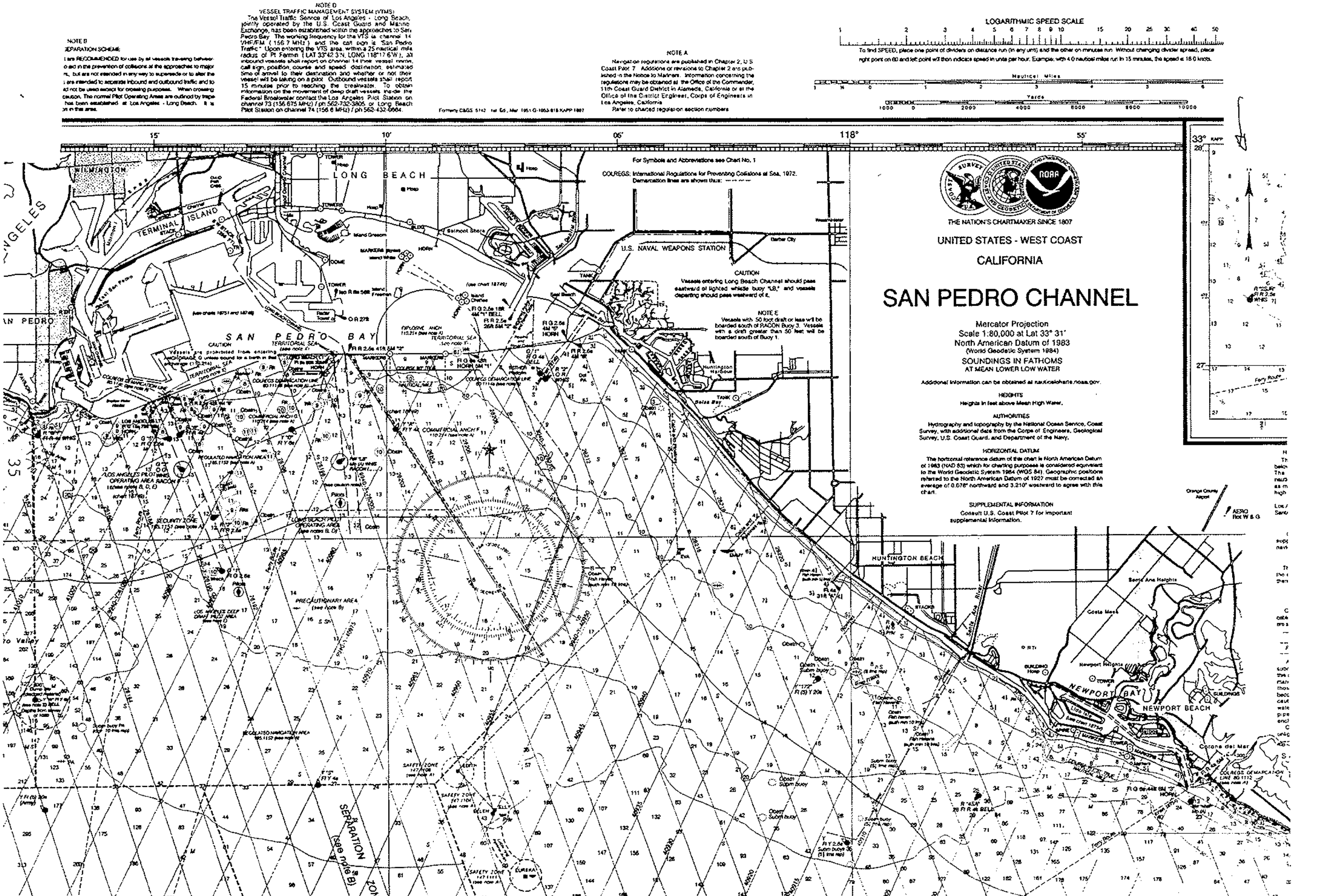

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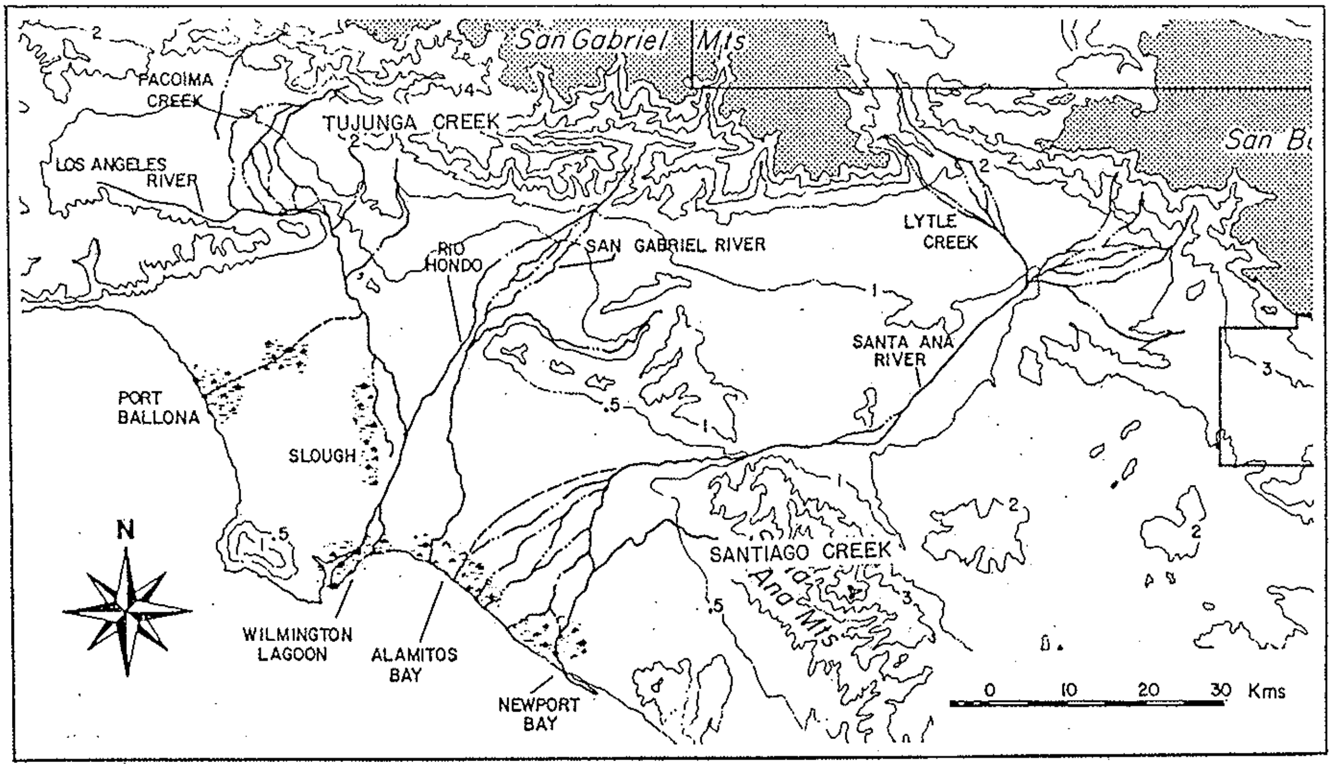

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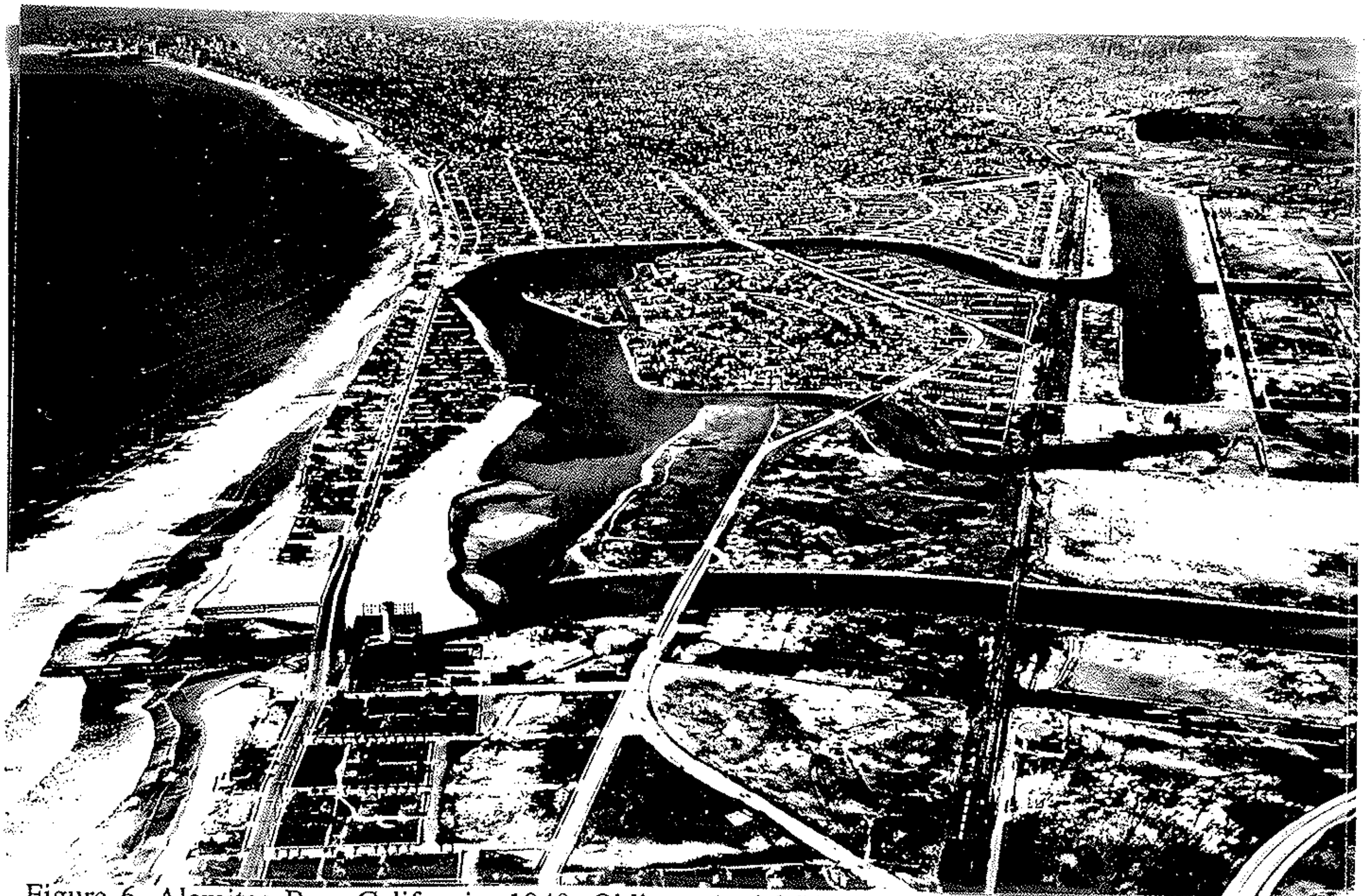

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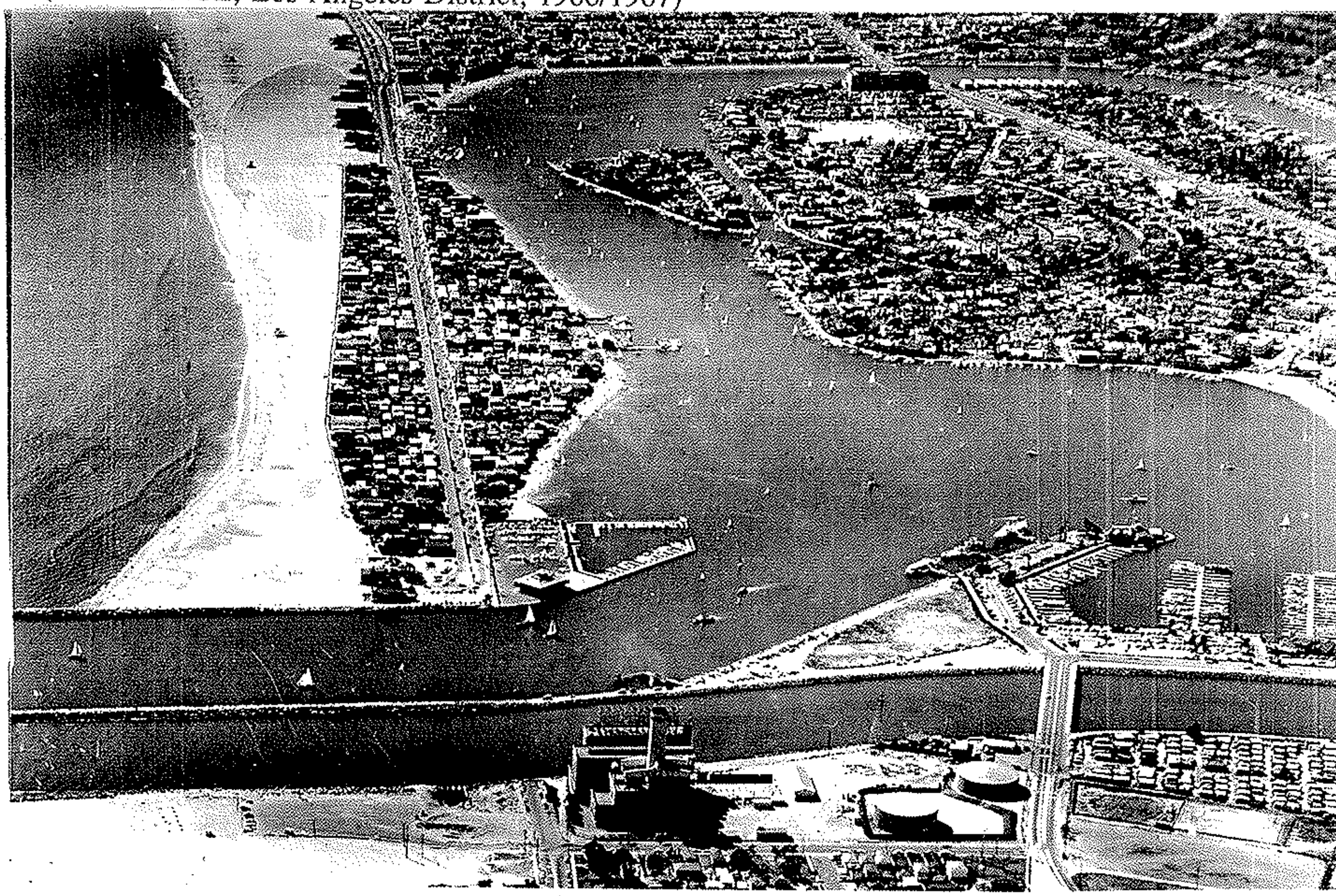

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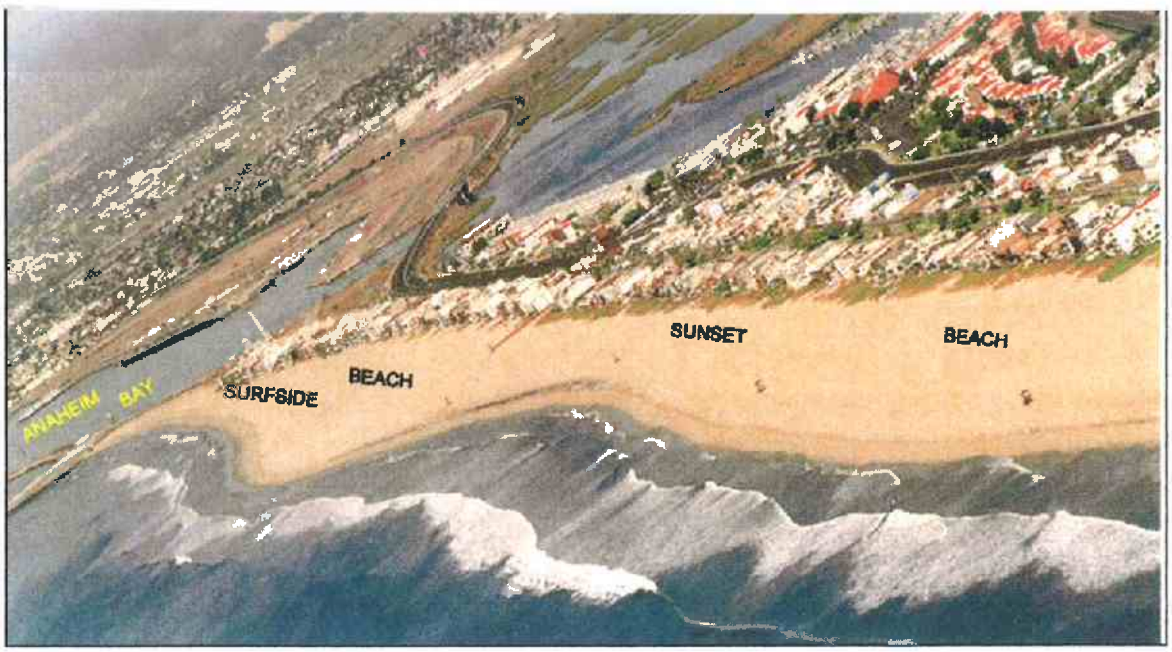

PHOTO TAKEN ON NOVEMBER 12, 1998

Sources: UCLA Department of Geology, Spence Collection
Noble Consultants Inc.

Figure 9. Aerial Photo of Surfside-Sunset Area, looking NE from Offshore. (From USACE, Los Angeles District, Dec. 2002)

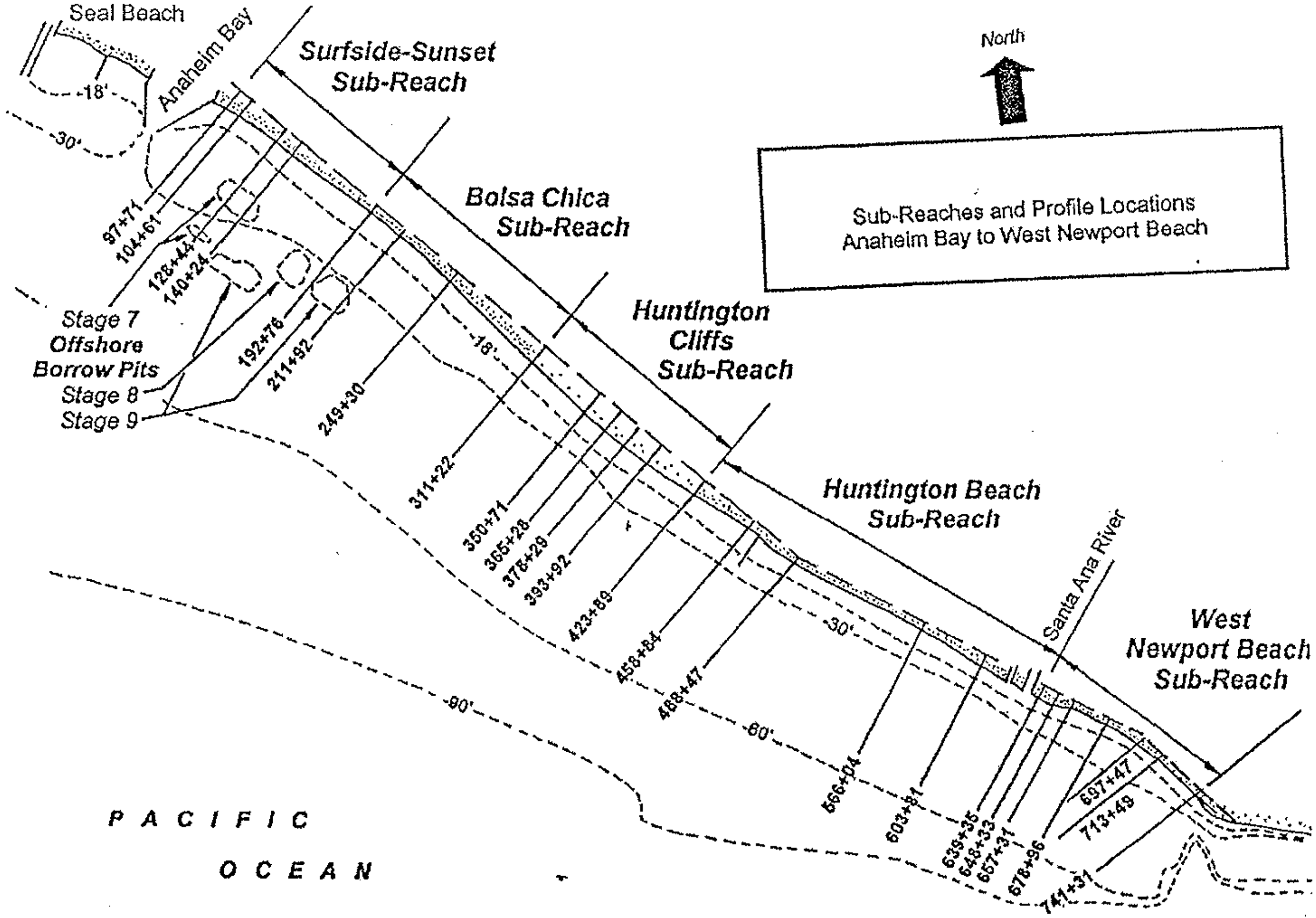

Figure 10. Survey Transect Locations, Huntington Beach Littoral Sediment Sub-cell (Anaheim Bay to Santa Ana River Mouth). (From USACE, Los Angeles District, Dec. 2002)

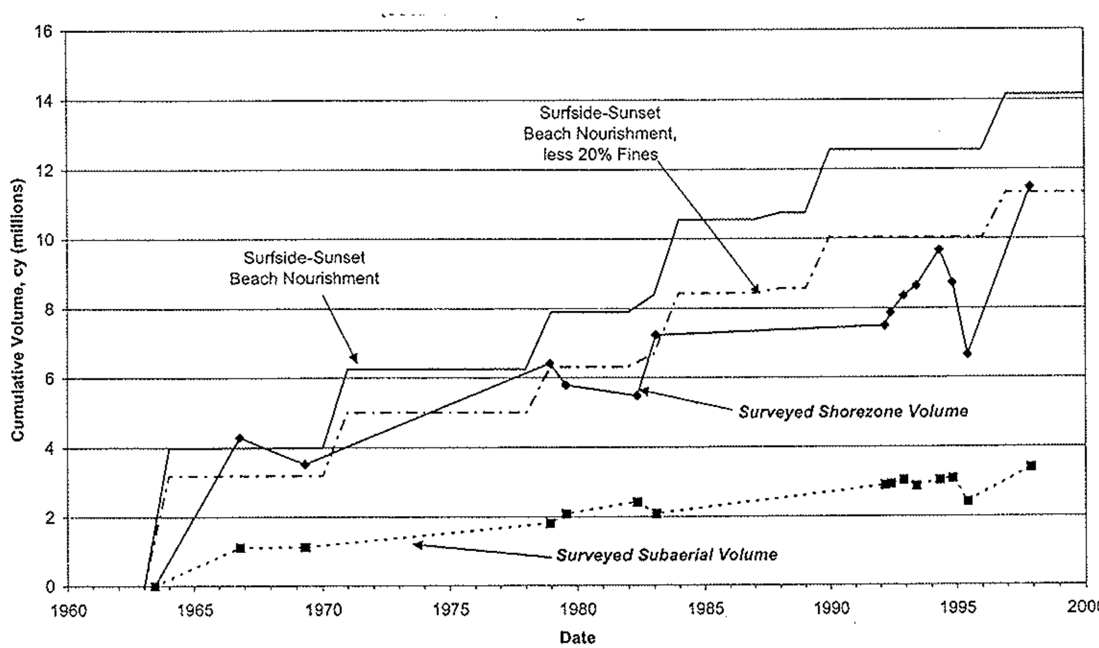

Figure 11. Time History of Cumulative Volumes (Shorezone Nourishment), 1963-1997. (From USACE, Los Angeles District, Dec. 2002)

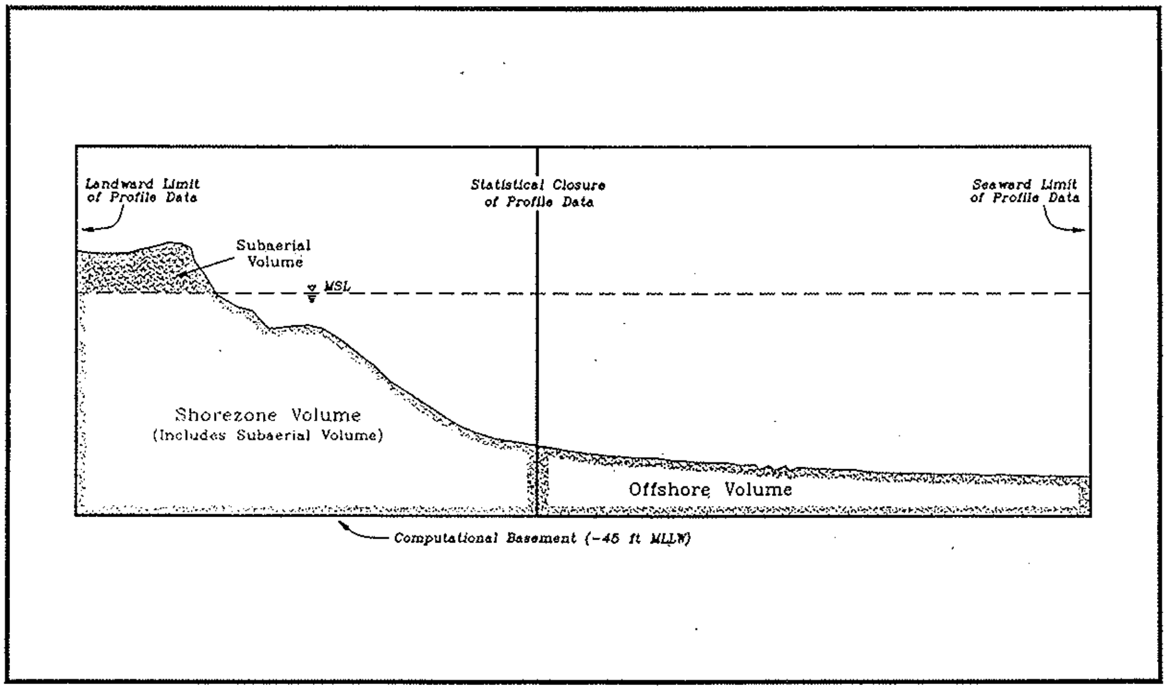

Figure 12. Cross-shore Regions Utilized for Volume Computations; Definition Sketch. (From USACE, Los Angeles District, Dec. 2002; Gadd, Leidersdorf, Hearon, Shak and Ryan, 2007)

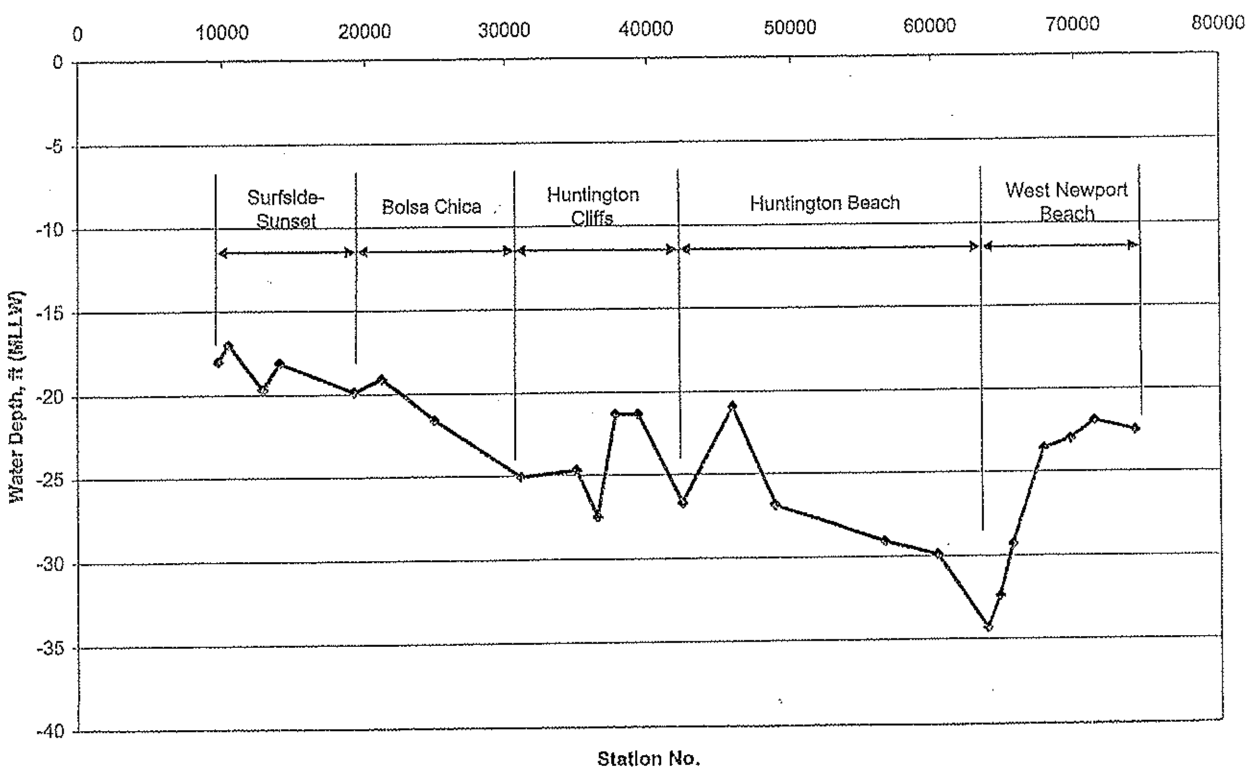

Figure 13. Depths of Statistical Closure, Huntington Beach Littoral Cell. (From USACE LAD, Dec., 2002; Gadd, Leidersdorf, Hearon, Shak, and Ryan, 2007)

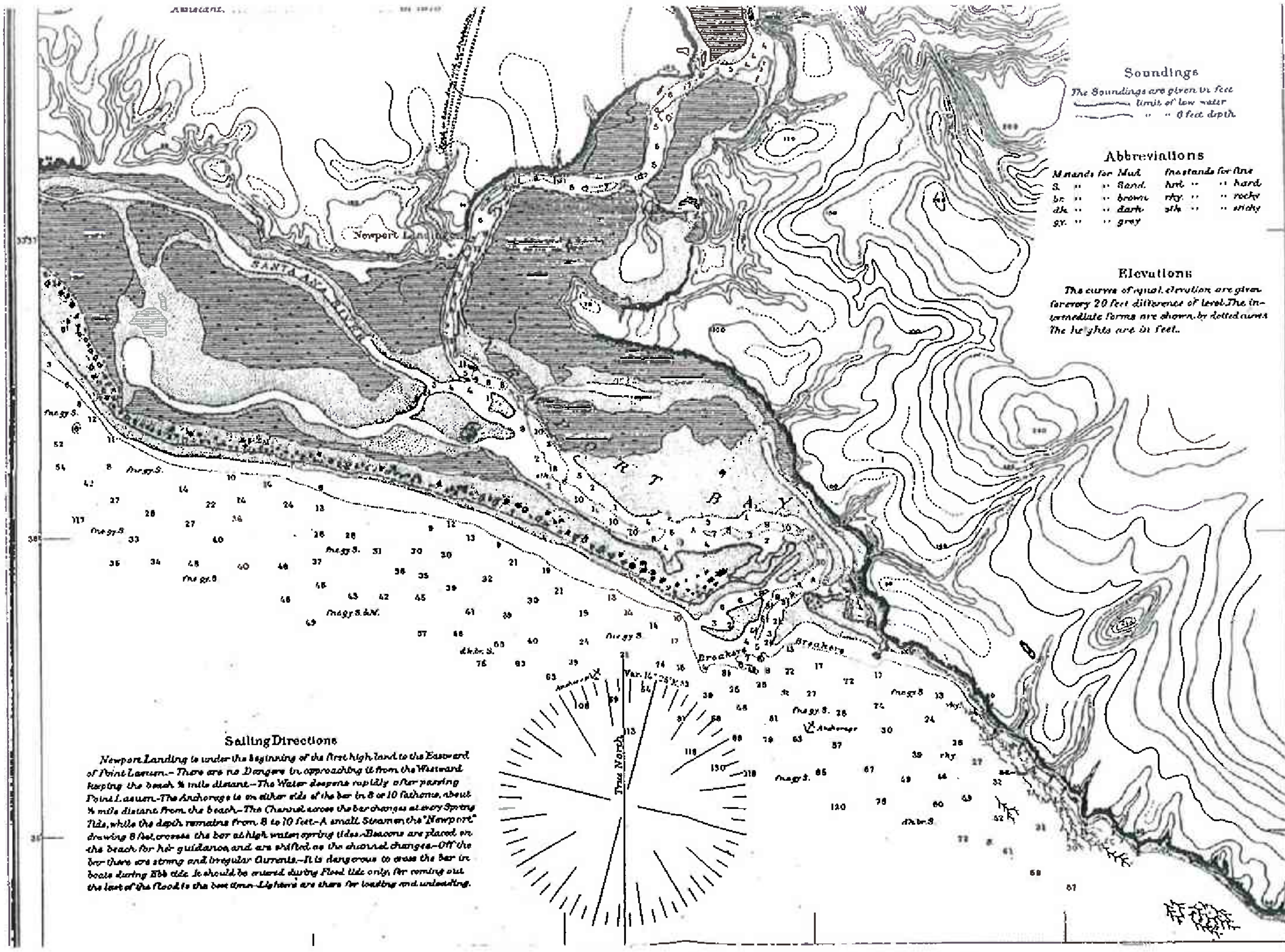

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Figure 14. *Newport Entrance, Los Angeles County, California, 1878*, U.S. Coast Survey, No. 670, Issued Nov. 1880; Copy of a Part of the Chart

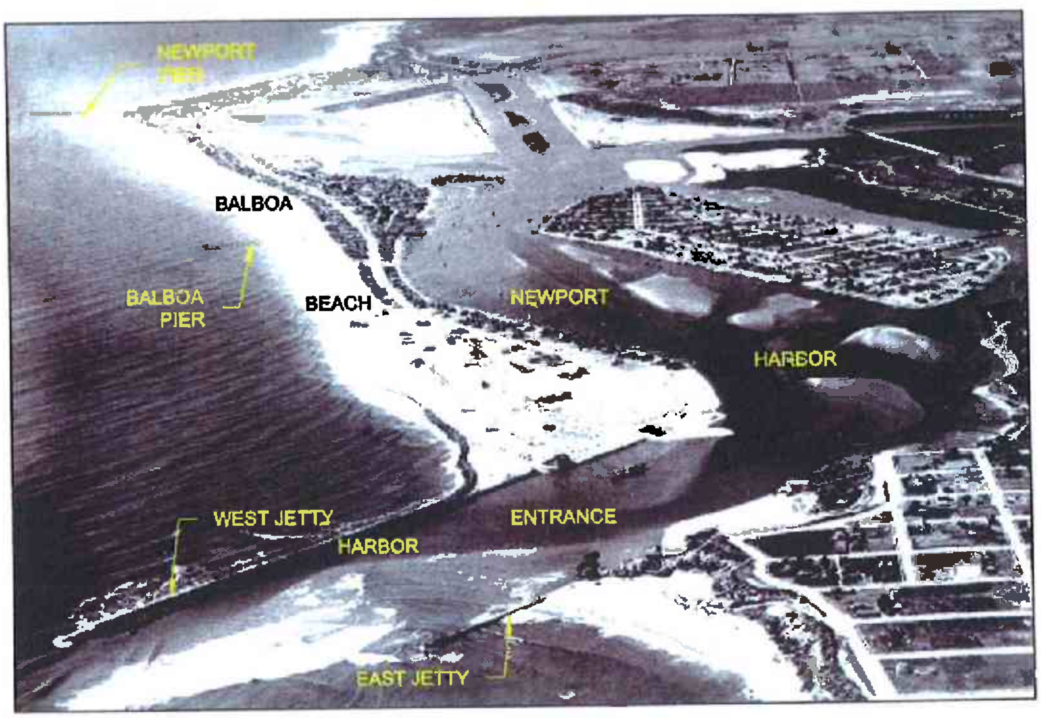


Figure 15. Newport Bay Entrance, Balboa Beach, to Newport Pier, Newport Harbor. Aerial Photo, 12 April 1928. (From USACE, Los Angeles District, Dec. 2002, Fig. 2-16)

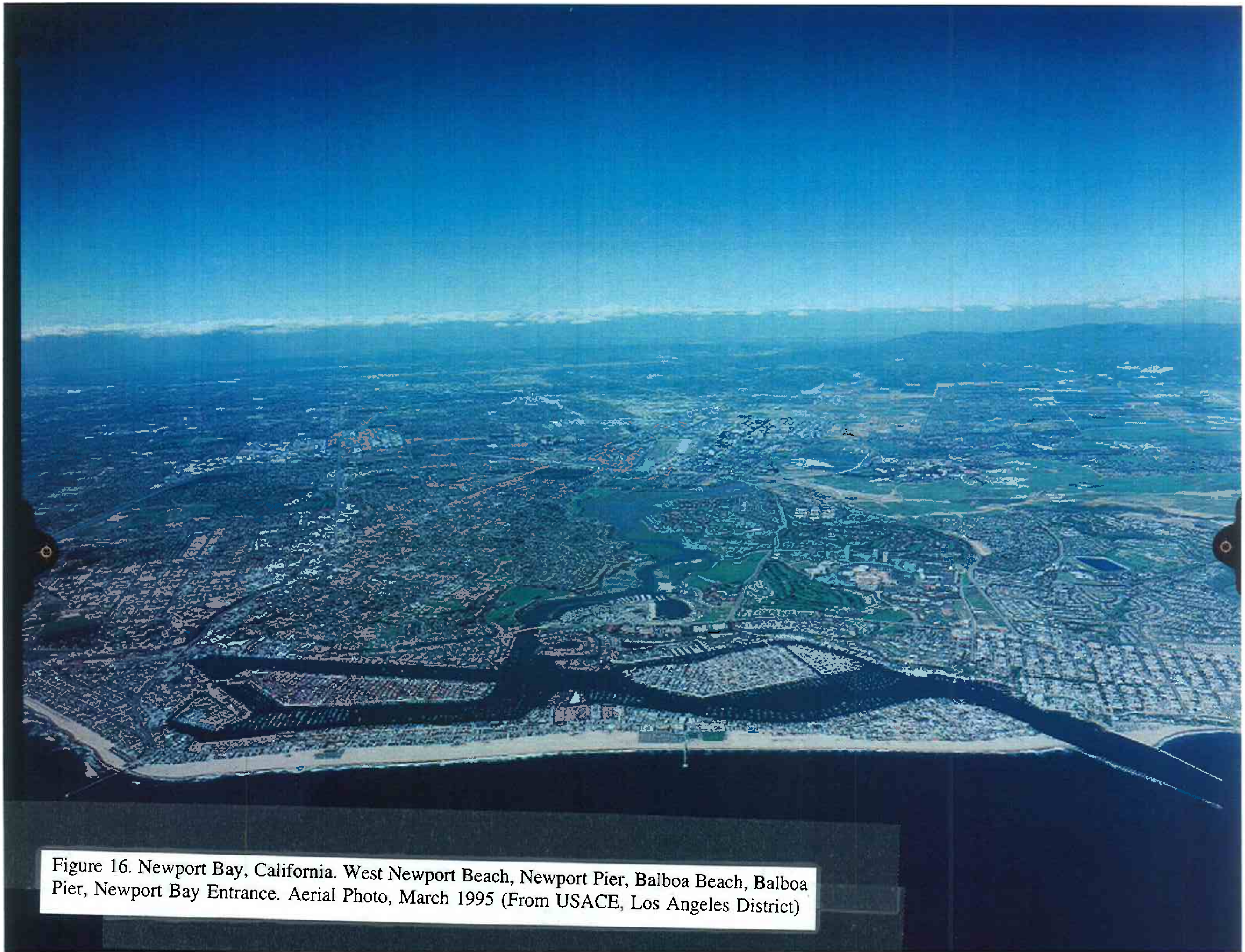


Figure 16. Newport Bay, California. West Newport Beach, Newport Pier, Balboa Beach, Balboa Pier, Newport Bay Entrance. Aerial Photo, March 1995 (From USACE, Los Angeles District)

5 VALUE ENGINEERING PAYS 4

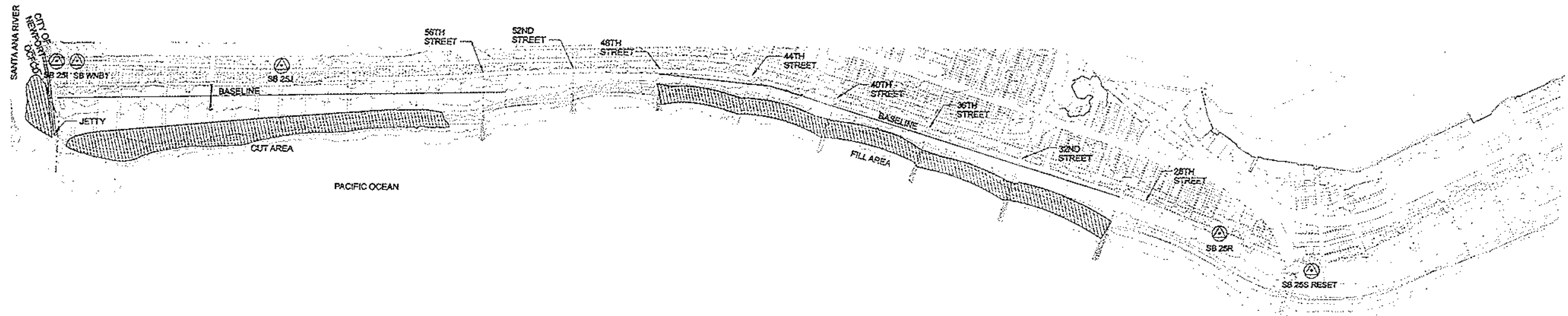
MOFFATT & NICHOL — U.S. ARMY ENGINEER DISTRICT, LOS ANGELES, CORPS OF ENGINEERS

PREPARED UNDER THE DIRECTION OF: COLONEL THOMAS H. MAGNESS, DISTRICT ENGINEER

SAN GABRIEL RIVER TO NEWPORT BAY
ORANGE COUNTY, CALIFORNIA
NEWPORT BEACH SAND BACKPASSING
SURVEY CONTROL

REVISIONS

NEWPORT BEACH SAND BACKPASSING
BEACH NOURISHMENT, STAGE 12
SAN GABRIEL RIVER TO NEWPORT BAY



STATION	NORTHING	EASTING	ELEVATION	TYPE OF MARK
SB 25I	2,177,209.217	6,042,221.266	14.72'	3 1/2" BRASS DISK
SB 25J	2,175,959.131	6,043,900.725	10.28'	NAIL
SB 25R	2,169,563.577	6,050,198.558	11.51'	3 1/2" BRASS DISK
SB 25S RESET	2,168,772.334	6,050,710.725	11.52'	3 1/2" BRASS DISK
SB WNB1	2,177,099.053	6,042,374.383	12.39'	2" BRASS DISK

SYMBOL LEGEND

MONUMENT SYMBOL

NOTES:

1. COORDINATES ARE BASED ON CA STATE PLANE, NAD 1983, ZONE 6, FEET.
2. VERTICAL DATUM IS MEAN LOWER LOW WATER (EL=0.00 FT), 1983-2001 EPOCH.
3. ALL DIMENSIONS ARE IN FEET UNLESS OTHERWISE INDICATED.
4. CONTOURS INDICATE THE GENERAL CONDITIONS EXISTING ONLY AT TIME OF SURVEY, SEPT. 2008.

SCALE: 1"=500'

SAFETY PAYS

Figure 17. West Newport Beach, CA. Sand Backpassing, Beach Nourishment, Stage 12, San Gabriel River to Newport Pier. (From USACE, Los Angeles District, 2009)