CHAPTER 208

SEDIMENT TRANSPORT PROCESSES AT OCEAN BEACH, SAN FRANCISCO, CALIFORNIA

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The San Francisco estuary inlet and tidal bar is a highly complex system that strongly influences littoral processes on adjacent beaches. Ocean Beach is about 4 miles long, located near the entrance to the estuary (Figures 1 and 2). The purpose of the study was to investigate the extent and causes of shoreline variability at Ocean Beach, and identify possible sand transport processes and directions based on available information (Moffatt & Nichol Engineers, 1994; 1995).

Geographic Description of Vicinity

Ocean Beach is a sandy beach on the west side of San Francisco, California, USA (Figures 1,2 and 3). A linear dune behind the beach forms an embankment covering the West Side Sewer Transport Box, supporting the Upper Great Highway, and protecting the urban residential area from the Pacific Ocean. Seawalls have been constructed where the embankment eroded frequently. These structures are the most obvious indications of impacts by man dating back to the late 1800's (O'Shaughnessy,1924; Olmsted and Olmsted,1979; Berrigan,1985a; O'Doherty,1994). Perpendicular to the Great Highway are a series of streets named alphabetically from north to south (eg. Noriega, Ortega, Pacheco, Quintara, etc.) which are often used as location references.

The offshore bathymetry and shoreline to the north and south are very irregular, affecting wave propagation and littoral sand transport (Figure 1). The Golden Gate is located to the north of Ocean Beach. This channel connects San Francisco Bay with the Pacific Ocean. The large tidal prism (2.3×10^9 cubic meters, m^3, for a typical tide range of 1.5 meters) and rocky shoreline results in a relatively constricted channel (0.084 square kilometer) and strong currents (typical peaks about 10 kilometers per hour) (USACE, 1990).

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The San Francisco Bar is a horseshoe-shaped, sandy shoal with a radius of about 5 kilometers (3 miles). The Bar crest depths are as shallow as 7.3 meters (24 feet) at low tide. Every winter, larger storm seas and swells induce wave breaking along the crest of the Bar. There are several sand shoals just east of the Golden Gate in San Francisco Bay. Sand beaches exist along the south boundary of the Golden Gate.

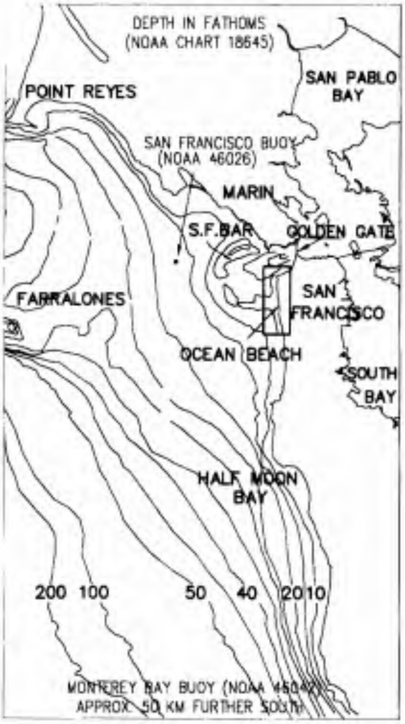


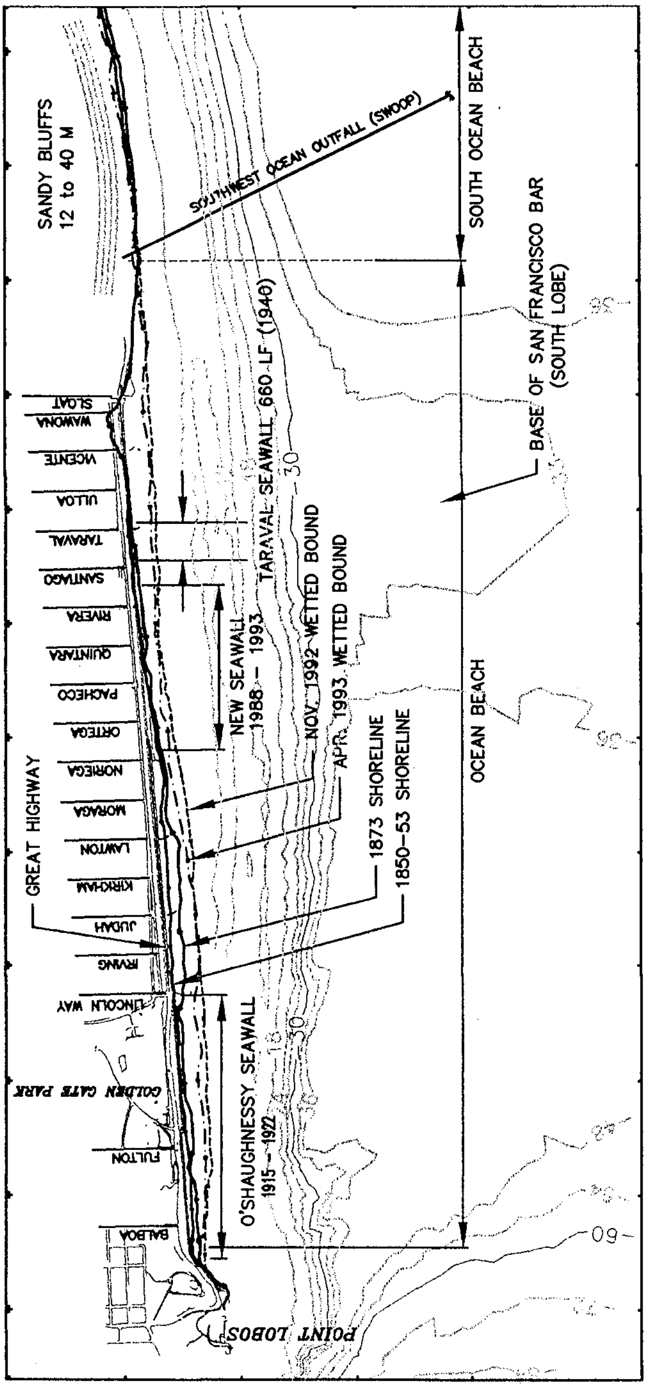
Figure 1: Site Location

Figure 2: Aerial Photo of Site

Sediment Characteristics

Median grain sizes of sand samples from the vicinity were reported by Trask(1958), Moore(1965), Johnson(1971), USACE(1974;1993), Galvin(1979a), Woodward-Clyde Consultants (1979), Ecker(1980), and Noble(1985). At Ocean Beach, the median grain sizes were typically 0.2 to 0.6 millimeters (mm), but occasionally between 0.6 and 1.6 mm. Grain sizes vary significantly along the beach and seasonally, with larger grain sizes in the spring (Trask, 1958; Galvin,1979), especially near the base of the San Francisco Bar. Median grain sizes on the crest of the San Francisco bar are the smallest (0.1 to 0.2 mm), with coarser sizes inside the crest (0.2 to 0.7 mm). Median grain sizes inside the Golden Gate are similar.

Johnson (1971) summarizes mineralogy studies in the area.



NOTES:

1. DEPTH CONTOURS (FT) SHOWN BASED ON MEAN LOWER LOW WATER, FROM 1954 – 1956 HYDROGRAPHIC SURVEY.
2. PLANIMETRIC MAP OBTAINED FROM HAMMON, JENSEN & WALLEN, NOVEMBER 1992.

Figure 3: Study Area

Similar heavy mineral content in the sands were found at Ocean Beach and nearby areas (San Francisco Bar, Golden Gate, and beaches south to Pedro Point), but not for offshore areas or beaches to the north or farther south. Johnson(1971;1977) concluded that there was probably very little net sand transport at the boundary of the area defined by the San Francisco Bar and Entrance, and the beaches south to Pedro Point.

Currents

Detailed data regarding tidal currents and sediment grain sizes can be found in Enclosure 1 of USACE (1974). Tidal current charts show directions that "fan-out" to cross the San Francisco Bar roughly perpendicular to the crest. At Ocean Beach, ebb tide currents are roughly parallel to shore and southward. Flood tide currents are roughly northward. Due to the diurnal inequality, the strongest currents are associated with the larger ebb tides. Peak annual tide ranges are about 2.5 to 2.8 meters, with peak ebb currents between 2 and 4 kilometers per hour. During these strong flows, large eddies form near headlands, causing nearshore currents to flow in the opposite direction. Currents in the surf zone are strong, complex and variable. Detailed measurements are not available.

Waves

Ocean Beach is exposed to storm seas and swell generated in the Northern Pacific, and swell generated in the Southern Pacific. Large wave power is incident, with the greatest in the winter (Johnson,1977; Woodward-Clyde Consultants,1978; Cross,1980; Berrigan,1985b, Wiegel,1992). Wave refraction causes focusing of incident waves at Ocean Beach for most directions and especially for longer wave periods (Street, Mogel and Perry,1970; Woodward-Clyde Consultants,1978; USACE,1993). Long period waves begin to refract around the 200-fathom (360 meters) line noted on Figure 1. The complex bathymetry results in multiple wave travel paths incident to Ocean Beach, and exposure to waves incident from north of the geometric shadow formed by Point Reyes. Refraction over the San Francisco Bar contours causes a focusing of wave energy near the base of the Bar, even for relatively short wave periods (Figure 4). Figure 2 is a high-altitude photograph which shows wave crossings due to refraction (see also, Vincent et. al., 1994). The result is an amplified breaking wave height at the location of wave crossing, resulting in a very peaked wave form (Figure 5, Battalio, 1994).

Prior estimates of wave-induced alongshore sand transport do not agree in direction nor magnitude. Estimated rates are typically around $5x10^5$ to $1.5x10^6$ m^3/yr ($7x10^5$ to $2x10^6$ cubic yards/yr, yd^3/yr) for the gross, and zero to $6x10^5$

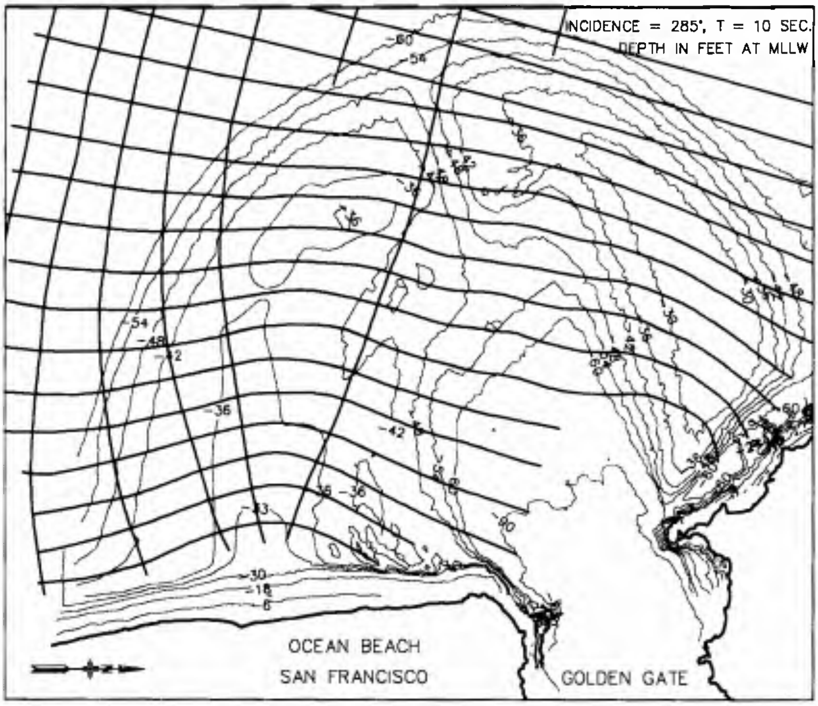


Figure 4: Wave Refraction Over San Francisco Bar (Source Woodward Clyde Consultants, 1978)

Figure 5: Grant Washburn Observes Breaking Wave Heights near Taraval Street, Ocean Beach, San Francisco, (Winter 1992). For scale, the surf board is 9 feet long. Photo: Tim Britton

m^3/yr ($8x10^5$ yd^3/yr) for the net (Street et. al.,1970; Kamel,1962; Johnson,1979; USACE,1979; Galvin,1979; Domurat, Pirie, and Sustar,1979).

A five-year data set of daily visual observations of breaking wave heights was reviewed (Washburn, 1996). Table 1 summarizes the cumulative distribution of breaking wave heights from these data, which were observed near the base of the San Francisco Bar (Taraval Street). These observations were compared to deep water significant wave heights recorded by the San Francisco Buoy and the Monterey Bay Buoy (see Figure 1 for locations): A time series correlation analysis produced coefficients of 0.79 and 0.76, respectively, indicating a strong correlation (maximum coefficient is 1.0).

Table 1: Cumulative Distribution of Breaking Wave Heights, Taraval Street, Ocean Beach (1991-1996)

Breaking Wave Height Meters	(Feet)	Frequency of Occurrence Larger Waves (% of Daily observations)
1.8	(6)	50%
3.0	(10)	25%
4.6	(15)	10%
7.3	(24)	1%

The method of Hands & Allison (1991) was used to gage the potential for onshore sand transport from the Bar to Ocean Beach. An average wave period of 12 seconds, a depth of 9 meters, and the cumulative distribution given in Table 1 were used. Calculations show a strong potential for onshore sand transport, as concluded by others (Kamel, 1962; Galvin, 1979).

Wind

Strong onshore (mostly northwest) winds occur at Ocean Beach. Prior to major development in the 1900's, the area behind Ocean Beach was an extensive dune field (Olmsted and Olmsted,1979). Sand losses due to inland transport by wind are estimated to be zero to $23x10^3$ m^3/yr ($30x10^3$ yd^3/yr) prior to 1975, and zero to $7.6x10^3$ m^3/yr ($10x10^3$ yd^3/yr) since then. The reduction is based on the City's practice of returning sand to the beach since 1975.

Man's Activities

Significant beach and dune fill occurred during the period 1882 to 1929, when the natural dunes were re-graded to form a straight embankment for the shore-parallel Great Highway (Olmsted and Olmsted,1979). This resulted in a seaward shift of the shoreline of about 60 to 90 meters (200 to 300 feet) (Figures 3 and 6). The estimated net volume changes to the beach and dunes by man since 1929 were summarized for the sediment budget (Table 3). Comparison of the shoreline data with the timing and location of sand placement indicates a northward littoral drift from the base of the Bar, which agrees with Johnson (1979).

The need for safe navigation to and from San Francisco Bay requires a dredged channel through the San Francisco Bar. The Bar Channel is authorized to a depth of 17 meters (55 feet) below mean lower low water. Since the Bar Channel was last deepened in 1975, annual dredging has totaled about $4.6x10^5$ m^3 ($6x10^5$ cy) of sand. The sand is dumped on the south part of the Bar (see Figure 10). Prior to 1971, the dredged sand was reportedly dumped about one mile southwest of the Bar Channel entrance in about 24 meters (80 feet) of water. The dump location was changed so that the sand would stay in the littoral zone (USACE, 1974).

Prior to 1971, at least 20 million m^3 (26 million yd^3) of sand was dredged. Since 1971, about 11 million m^3 (14 million yd^3) were dredged from the channel area and reportedly placed near the crest of the south side of the Bar: Of this total, about 4.6 million m^3 (6 million cy) was attributed to deepening of the channel.

Shoreline, Dunelines, and Related Volume Changes

Shorelines and toe-of-dune lines from historic maps and aerial photographs were used to investigate changes and as input to the sediment budget analysis. Five shorelines digitized from smooth sheets for the period 1850 to 1944, and eleven shorelines and toe of dune positions from aerial photographs for the period 1938 to 1993 were mapped (Moffatt & Nichol, 1994). The mean high water shoreline was used from the maps. The wetted bound visible in the aerial photos was used to estimate the shoreline position, which was found to approximate the Mean Higher High Water elevation of about +1.8 meters (6 feet) Mean Lower Low Water datum.

Time histories of the shoreline positions and beach widths for Ocean Beach and South Ocean Beach are shown in Figures 6 and 7. The Ocean Beach data show a large seaward offset between 1900 and 1929, while South Ocean Beach data do not. This is attributed to the construction of the embankment supporting the Great Highway, and related beach nourishment. The Ocean Beach data show large fluctuations about an accretion trend, while South Ocean Beach data show smaller fluctuations about a slow erosion trend. Both areas show erosion to the early 1970's, and a recovery in recent years.

Beach and shoreface volume changes were estimated by applying a conversion factor of volume change per beach area change. A range of 8 to 14 m^3/m^2, (1.0 to 1.7 yd^3/ft^2) of beach change was used to calculate the values for Beach and Shoreface in Table 3. The higher value was developed based on a review of profile "closure" elevations and the assumption that the shoreface geometry remains essentially constant as the shoreline migrates. The minimum conversion factor was based on the assumption that shoreline changes were due to erosion of sand placed by man on the upper beach and dune, per Galvin(1979) and Ecker (1980). Volume changes for the dune face were calculated using a conversion factor that ranged between zero and 6 m^3/m^2 (0.74 yd^3/ft^2) of dune line change.

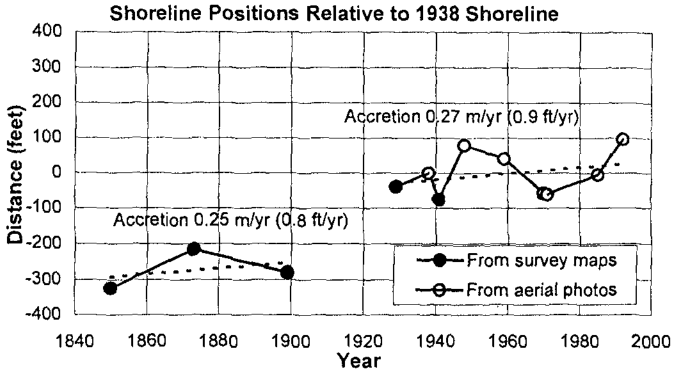


Figure 6: Shoreline Change Data Ocean Beach

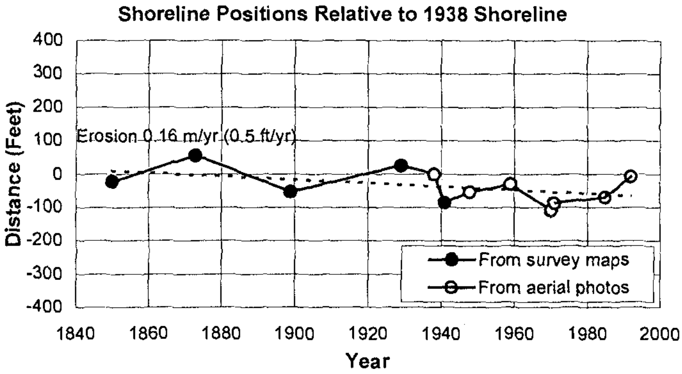


Figure 7: Shoreline Change Data So. Ocean Beach

San Francisco Bar Depth Changes

Prior studies of historic changes to the San Francisco Bar have been identified by Gilbert(1917), Homan and Schultz(1963), and Johnson(1965). Figure 8 shows the depths surveyed in 1900. Figure 9 shows the depths surveyed in 1956, and major depth changes since 1900.

Prior to 1900, the Bar had a relatively consistent "cuspate" shape. By 1956, outer portions eroded and inner portions accreted. Significant changes include the dredged channel, which is deeper, the area closer to Ocean Beach, which is shallower, and the Bar crest, which

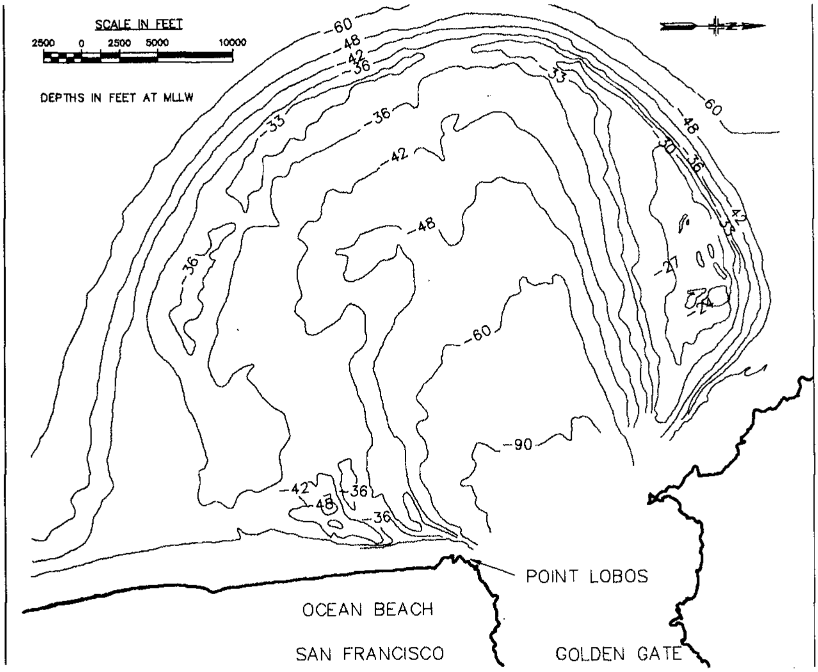


Figure 8: Bathymetry of San Francisco Bar, Circa 1900

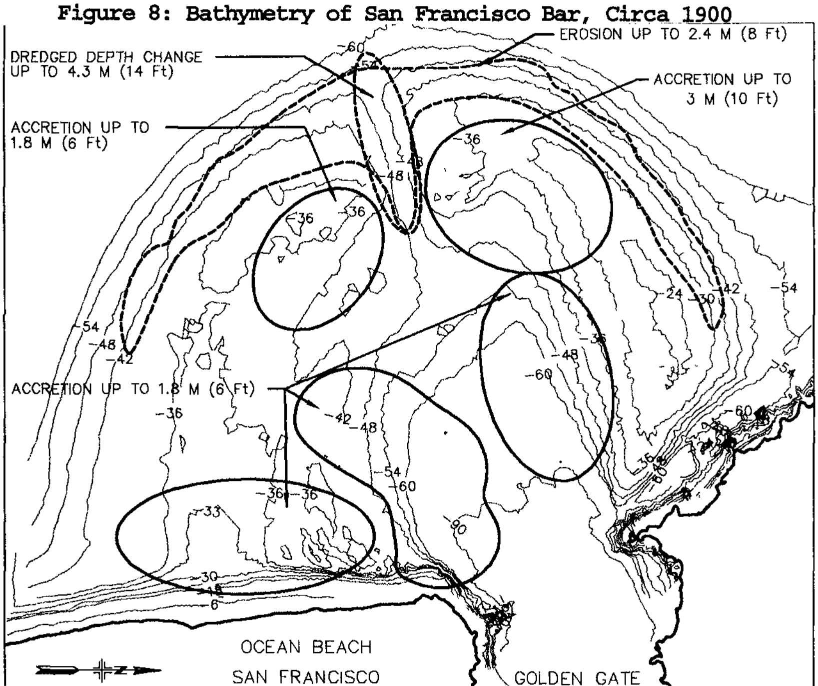


Figure 9: Bathymetry of San Francisco Bar, Circa 1956 and Major Depth Changes 1900 - 1956

generally shows a radial "shrinking."

Volume changes calculated for the San Francisco Bar by a comparison of the 1900 and 1956 survey maps are provided in Table 2. The Table includes volume changes adjusted for two arbitrary systematic elevation corrections.

Since no recent survey is available, and due to the sensitivity to vertical control, the Bar changes were not directly incorporated into the sediment budget.

TABLE 2: San Francisco Bar Volume Changes and Sensitivity to Systematic Elevation Corrections

LOCATION	VOLUME CHANGES FOR 1900-1956 TIME PERIOD Million Cubic Meters		
	Calculated	0.09 m correction	0.12 m correction
Four Fathom Bank	4.5	0.0	-1.5
Channel	-10.2	-12.4	-13.2
South Bar	19.2	14.6	13.1
Net Change	13.5	2.2	-1.5
Average Rate (m3/year)	241,000	39,000	-28,000

Sediment Budget Analysis

The sediment budget was developed to best use the available data, as summarized in Table 3. A range of values were used to reflect the uncertainty of the available data, and to facilitate a sensitivity analysis. The sediment budget analysis was applied to the Ocean Beach shoreface, beach, and dune face.

Based primarily on the historic shoreline positions, the sediment budget analysis was applied to the time period of 1929 to 1971 and 1971 to 1992. By 1929, the shoreline and embankment had been established roughly in its present location. An erosion trend dominated to 1971, becoming an accretion trend to the present. Starting in 1971, sand dredged from the Bar Channel was disposed on the Bar offshore of Ocean Beach, and the Channel was deepened significantly. Starting in 1975, wind blown sand was returned to the beach by the City.

For 1929-1971, a net deficit of 1.3×10^4 to 1×10^3 m3/yr (1.7×10^4 to 1.4×10^3 yd^3/yr) is calculated (**Subtotal (I-II)** in Table 3). This range is small, and within the possible range of wind-induced losses inland, so that it is possible to balance the budget for this time frame by assuming zero net sand transport at the area boundaries, or that net input at one boundary (onshore from the Bar), is balanced by losses past other boundaries (north past Point Lobos, and/or south past South Ocean Beach). Local knowledge indicates erosion is occurring in the area south of Ocean Beach, while sand accumulation is a problem in several areas along the north waterfront of San Francisco. It is therefore considered more likely that losses from Ocean Beach are passing Point Lobos and migrating into San Francisco Bay.

TABLE 3: Sediment Budget for Ocean Beach, San Francisco (Annualized for Listed Time Periods)

No.	ITEM	RANGE OF SAND VOLUME CHANGES (Thousands of Cubic Meters per Year)					
		1929-1971		1971-1992		1929-1992	
		Low	High	Low	High	Low	High
I	**VOLUME CHANGES**						
1	Beach & Shoreface	(7.3)	(12.6)	103.4	175.9	29.6	50.2
2	Dune Face (data from 1938)	0.0	(3.1)	0.0	(10.9)	0.0	(5.7)
	Net Volume Changes	(7.3)	(15.7)	103.4	164.9	29.6	44.5
II	**SAND INPUT (LOSSES)**						
3	Net Beach/Dune Nourishment (+) Mining (-)	5.5	9.1	36.4	36.4	15.8	18.2
4	Wind Blown Loss to Inland	0.0	(23.7)	0.0	(7.3)	0.0	(18.2)
	Net Input (Losses)	5.5	(14.6)	36.4	29.1	15.8	0.0
	Subtotal (I - II)	(12.7)	(1.1)	67.0	135.8	13.8	44.5
III	**Estimated to Balance Budget**						
6	Minimum Northward Transport Past Point Lobos	(12.7)	(77.6)	(12.7)	(77.6)	(12.7)	(77.6)
7	Minimum Onshore Transport From San Francisco	0.0	76.5	79.7	213.4	26.6	122.1
	Subtotal	(12.7)	(1.1)	67.0	135.8	13.8	44.5
IIII	**Total (I - II - III)**	0	0	0	0	0	0

For 1971-1992, a net surplus of $6.7x10^4$ to $1.4x10^5$ m3/yr ($8x10^4$ to $1.8x10^5$ yd^3/yr) is calculated, which is a significant change from the previous period. This rate of input can only be explained by alongshore transport from the area south of Ocean beach, or onshore transport from the Bar. However, only the onshore transport potential from the Bar changed markedly around 1971, due to the change in dredging practices.

Postulated Rates to Balance Sediment Budget

The third part (**III**) of Table 3 shows one possible solution to the sediment budget. Assuming a range for onshore transport from the Bar during 1929-71 to be zero to $7.6x10^4$ m^3/yr ($1x10^5$ yd^3/yr), the loss due to alongshore transport past Point Lobos is calculated to be about the same as the input from the Bar. For the period 1971-92, the rate of alongshore transport past Point Lobos is assumed to be the same as for 1929-71. The required onshore sand transport rate from the bar is then calculated to be $8x10^4$ to $2.1x10^5$ m^3/yr ($1x10^5$ to $2.8x10^5$ yd^3/yr).

Figure 10 presents the 1971-92 rates and postulated sand transport for the Ocean Beach, Golden Gate cell. The net alongshore transport rate at Ocean Beach is estimated to be northward. The rate decreases with distance north, with sand accumulating in the beach and dunes. South of the base of the Bar, the net alongshore transport rate is unknown, but expected to be near zero.

The sand that passes Point Lobos is believed to mostly continue alongshore through the Golden Gate. Some is lost to maintenance dredging and dunes. The remainder is speculated to return to Ocean Beach by ebb tide currents, probably diverting from shore at several locations. Some or most of the sand is believed to migrate back to the San Francisco Bar prior to returning to Ocean Beach.

These rates are presented as long-term, average annual rates that could be substantially different in any particular year. Further study is needed, including

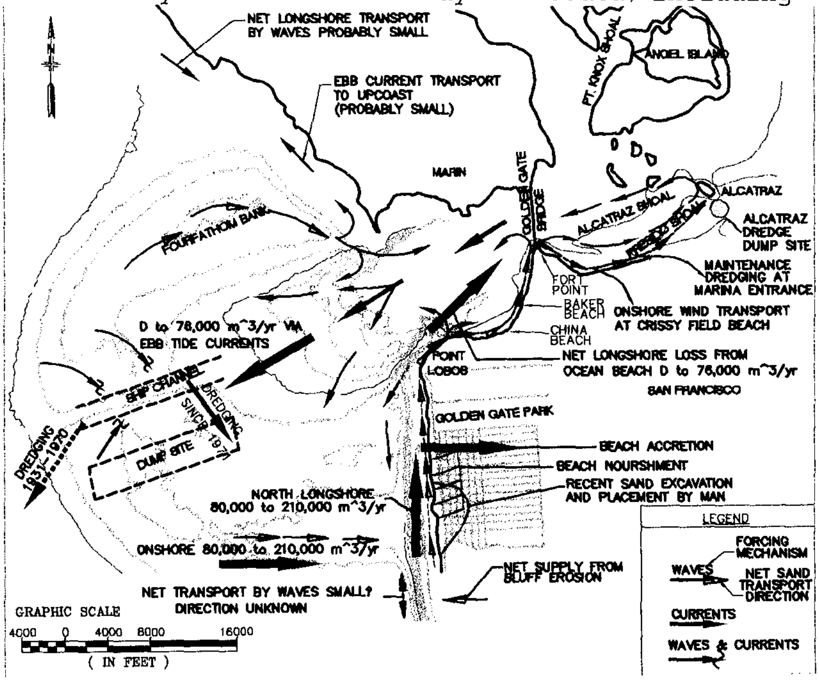


Figure 10: Residual Sediment Transport at Ocean Beach

recent Bar changes, sand transport and sediment budget in the Golden Gate area, and sand transport and sediment budget south of Ocean Beach to Pedro Point, Pacifica.

Acknowledgements

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and individuals familiar with the area (Dr. James Walker and Dr. Philip Williams).

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