1. INTRODUCTION

1.1 REGIONAL SEDIMENT MANAGEMENT

For social, recreational, economic, and environmental reasons, the coast of southern Monterey Bay is among the region's most prized natural resources. The beaches offer recreational activities and economic opportunities to Monterey Bay residents and visitors; they afford a natural barrier that protects the shoreline during storm events; they provide habitat for numerous shorebirds, including critical habitats for threatened or endangered species; and they are desirable places to live near, increasing property values and revenue for the community. Due to a persistent rise in sea level, changes in sand availability, and previous unsustainable public and private development practices, the southern Monterey Bay coastal dunes south of the Salinas River are eroding, on average, at the fastest rate in California (Hapke et al., 2006). Erosion compromises the ability of the dunes and beaches to buffer the oceanfront development and infrastructure from storms and flooding, to provide vital natural habitat, and to successfully accommodate recreation and tourism.

Along the California coast, state, federal, and local agencies are now attempting to address sediment supply and coastal erosion problems caused by human modification through Regional Sediment Management (RSM). RSM solves sediment-related problems by designing solutions that fit within a regional framework. RSM recognizes that sediment is a resource integral to economic and environmental vitality of coastal beaches, and sustainability can be achieved through beneficial reuse of littoral, estuarine, and river sediments. RSM in California is being facilitated through the California Coastal Sediment Master Plan (Sediment Master Plan) administered by the California Sediment Management Workgroup (CSMW).

Regional Sediment Management is a collaborative effort between federal, state, and local agencies, and non-governmental organizations to evaluate California's coastal sediment management needs on a regional basis (CSMW, 2006).
More information is available on the CSMW web-site (http://www.dbw.ca.gov/CSMW)

1.1.1 Southern Monterey Bay Coastal Regional Sediment Management Plan

The Association of Monterey Bay Area Governments (AMBAG) retained a team led by Philip Williams & Associates (PWA) to develop this Coastal Regional Sediment Management Plan

(Coastal RSM Plan) for southern Monterey Bay. The objective of the Coastal RSM Plan is to provide consensus-driven management and policy recommendations on ways to reduce shoreline erosion and restore and maintain coastal beaches through implementation of regional sediment management and beneficial re-use of sediment. Other potential solutions that don't involve beneficial reuse of sediment are being evaluated as part of the complementary effort by SMBCEW (see below).

The technical basis for the Plan is an understanding of the local sediment and coastal processes, erosion rates, and sediment budget. Using these data in combination with economic, environmental, and societal considerations, critical areas of erosion are identified, critical species and habitat are delineated, and recommendations are proposed for RSM. These recommendations are meant to inform the local decision making process to help maintain the beaches of southern Monterey Bay and other critical areas of sediment deficit, in order to sustain recreation and tourism, enhance public safety and access, and restore coastal sandy habitats. Other parts of this Coastal RSM Plan explore:

- economic benefits and costs of RSM in southern Monterey Bay
- permits required for planning and implementing RSM, and how to proceed through environmental review and regulatory compliance
- potential sources of funding for costs associated with managing sediment
- governance structure(s) applicable to southern Monterey Bay

This Coastal RSM Plan has been produced within the framework of the Sediment Master Plan (CSMW, 2006). Funding was provided by the California Department of Boating and Waterways (CDBW) on behalf of CSMW. In addition to the Plan's focus on how regional sediment management can help address coastal erosion problems within the region, it should also provide the benefit of enhancing the southern Monterey Bay region's ability to compete for limited state and federal funding for erosion control projects that involve sediment management. Both CDBW and the U.S. Corps of Engineers (major funding sources) are committed to regional sediment management, and may likely base future allocations of limited funding on whether a proposed project aligns with an approved Coastal RSM Plan.

This Coastal RSM Plan was also developed in close collaboration with the Southern Monterey Bay Coastal Erosion Workgroup (SMBCEW). The SMBCEW was initiated in 2005 by the Monterey Bay National Marine Sanctuary (MBNMS), in collaboration with state and local partners, as part of a process to update the Sanctuary's Management Plan. The SMBCEW was established to address the issues of shoreline erosion and armoring in southern Monterey Bay and to develop a regional planning approach. The goals of the SMBCEW are:

- compile and analyze existing information on coastal erosion rates and threats to private and public facilities within southern Monterey Bay
- identify and assess the range of options available for responding to coastal erosion

- develop a regional shoreline preservation, restoration, and management plan for responding to coastal erosion that minimizes environmental and socioeconomic impacts.

Since its inception the SMBCEW has completed several projects that feed into the RSM process and have been integrated into this Coastal RSM Plan. The results include information on critical areas of erosion (SMBCEW, 2006b), regulatory and policy considerations (SMBCEW, 2007a), and funding opportunities (SMBCEW, 2007b). It is anticipated that the SMBCEW would serve as a technical advisory committee to AMBAG in the proposed governance structure for implementation of this Plan.

These two efforts (Coastal RSM Plan and SMBCEW) are intended to be individual, yet complementary, components of a larger integrated approach for addressing sediment management and coastal erosion in the southern Monterey Bay region. The Monterey Bay National Marine Sanctuary is also funding a technical evaluation of alternative approaches to addressing coastal erosion in the region (i.e. those that have not been addressed in the Coastal RSM Plan process). This project will also be carried out under the direction of AMBAG and the SMBCEW. This Coastal RSM Plan provides a subset of solutions that the SMBCEW can then incorporate into an overall assessment of solutions to coastal erosion that works best for stakeholders within the southern Monterey Bay littoral cell, and provide a vehicle to enhance the region's ability to compete for limited state and federal funding for erosion control projects.

The retreat of the southern Monterey Bay shoreline creates complex management problems; property owners want to protect their homes and businesses, municipalities want to protect their tax base and infrastructure, sand mine owners want to continue to remove sand and generate income, environmental groups want to preserve habitat and minimize damage to the dunes and beaches, and resource managers want to balance public access and habitat protection. These broader shoreline management and coastal zone management challenges are beyond the scope of this Coastal RSM Plan, which focuses primarily on sand management and mitigation of shoreline erosion. Hence the Plan could be considered a component of the larger shoreline and coastal zone management efforts, including Land Use Plans, Local Coastal Programs, and the MBNMS Draft Management Plan.

This written Plan is one of three main deliverables. The other two are a searchable database of references relevant to southern Monterey Bay, and a set of GIS data files to complement the information provided here. The database and GIS data files are accessible on the CSMW web-site (http://www.dbw.ca.gov/CSMW).

1.2 GEOMORPHOLOGY

Monterey Bay is a lowland coastal embayment, bounded by resistant rock headlands at its north (Santa Cruz) and south (Monterey) ends (Figures 1 and 2). The shoreline between the Salinas

River mouth and Wharf II breakwater in Monterey is mainly composed of wide sandy beaches backed by relict (approximately 5,000 to 3,000 years old) sand dunes up to five miles wide and 150 feet high (Griggs and Patsch, 2005; Smith et al., 2005; Thornton et al., 2006). The sand dunes, referred to as the Flandrian and pre-Flandrian dunes, were deposited during the Quaternary. The seaward face of the dunes is an eroding bluff (Figure 3).

Figure 1. Location Map

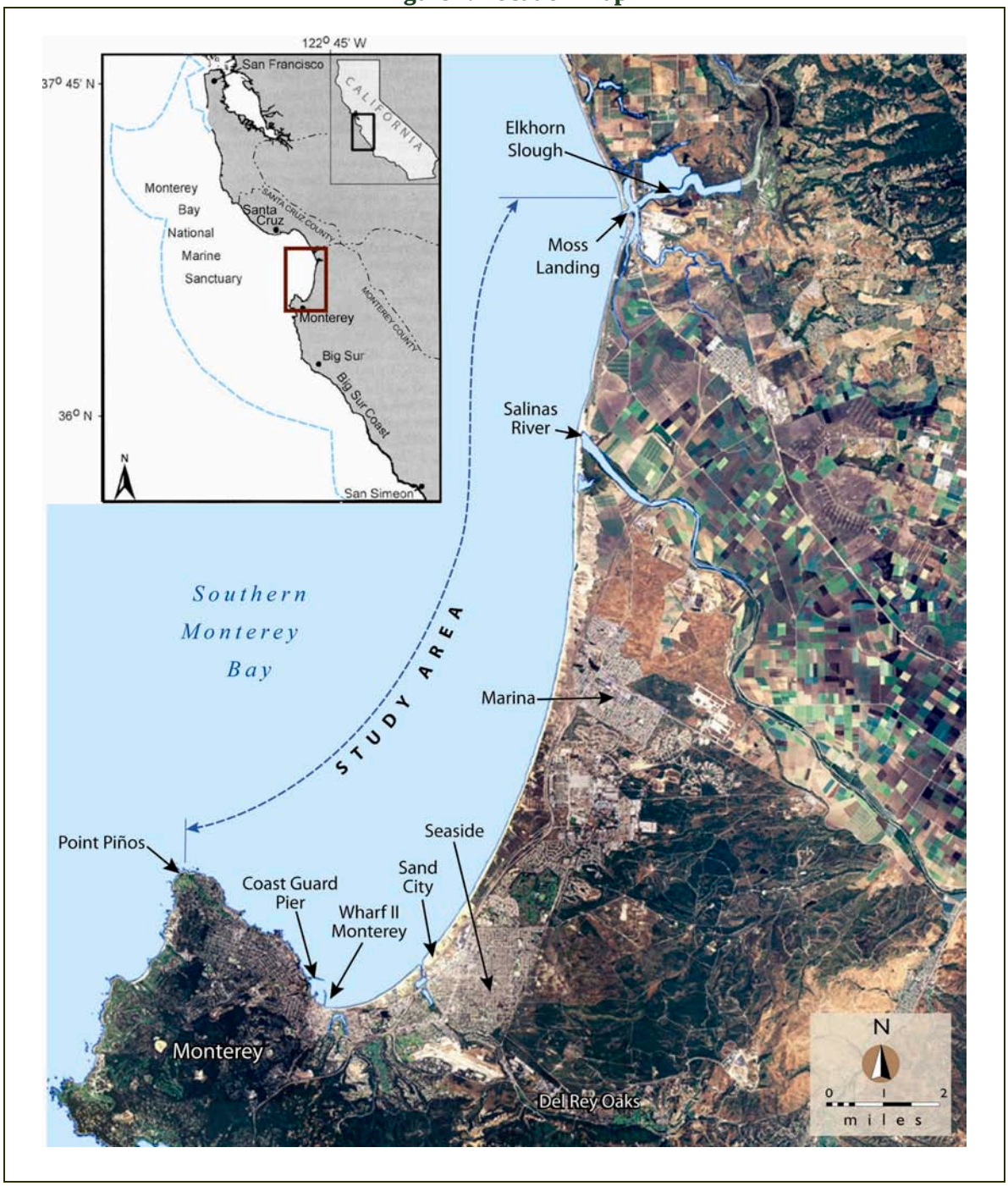
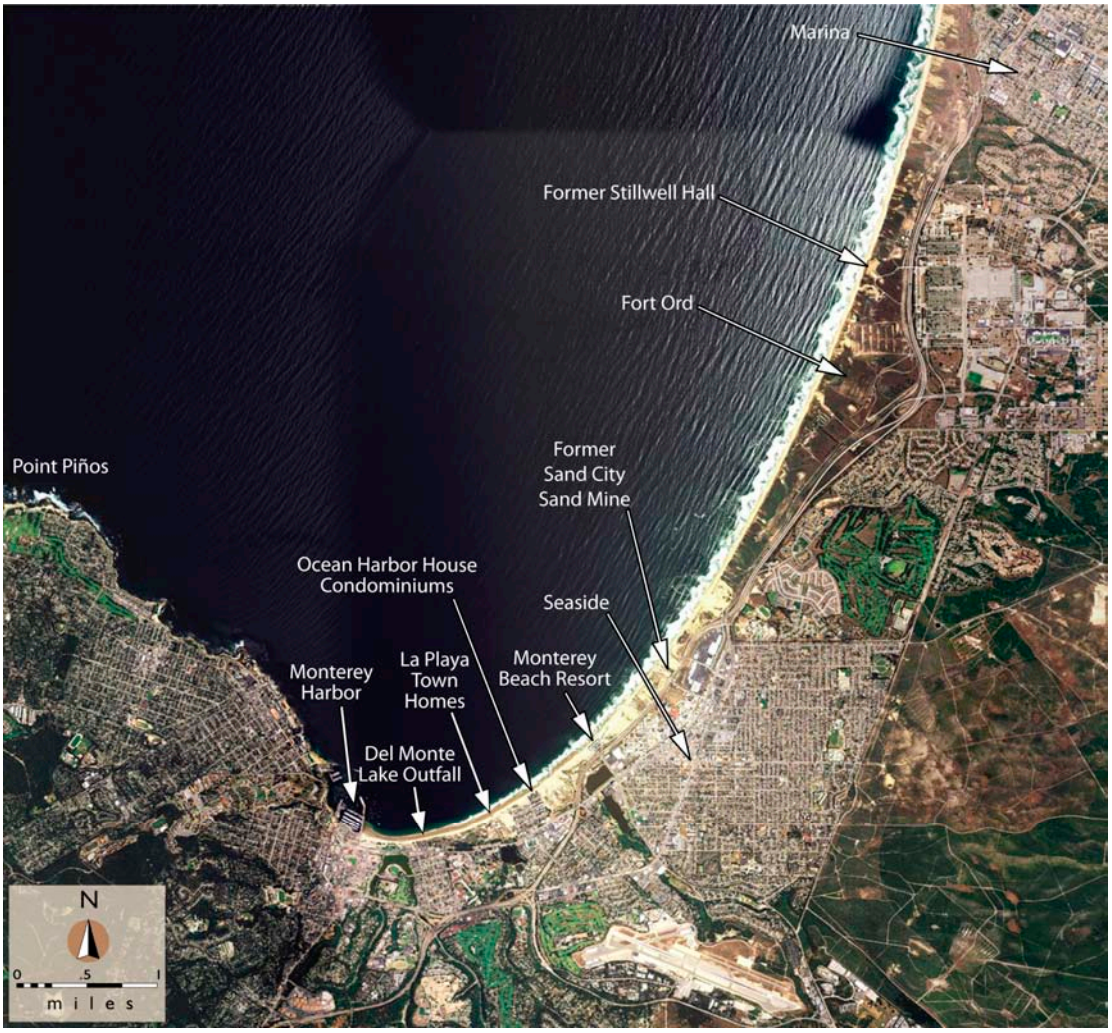


Figure 2. Locations at the Southern End of Southern Monterey Bay



Approximately 18,000 years ago, at a lower stand of sea level, the dunes extended seven miles seaward of the present day shoreline (Chin et al., 1988). Historically, the beaches of southern Monterey Bay were supplied by large volumes of sand from the watershed of the Salinas River, when the river had a much steeper gradient and a larger transport capacity for sediments. The abundant sand in combination with dominant onshore winds created an extensive dune field in southern Monterey Bay. During the Flandrian (last 10,000 years) the shoreline eroded in response to sea-level rise, migrating landward to its present position at an average erosion rate of approximately 2.3 ft/year. This value is a rough measure of the historic average erosion rate due to natural causes such as sea-level rise and offshore losses. Since the present rate of sea level rise is lower than the Flandrian rate, but erosion rates in general are higher than the historical mean

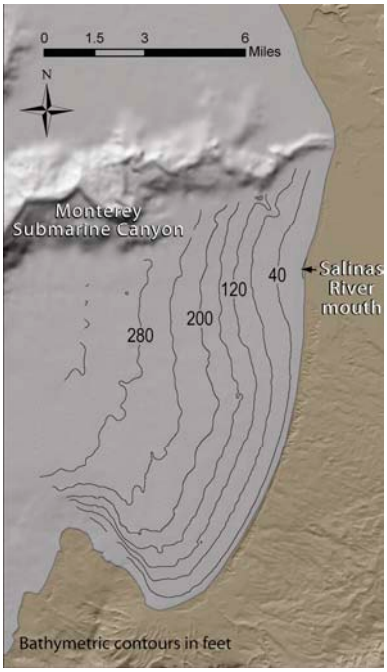
value, other processes have changed, such as a decrease in the amount of sand contributed by the Salinas River (Section 2.3.1) and sand losses due to sand mining (Section 2.5.4).

Figure 3. Eroding Dune Bluffs at Fort Ord

Photo taken: September 19, 2007 (Justin Vandever, PWA)

The shoreline from Moss Landing to two miles south of the Salinas River mouth is occupied by low relief recent, or active dunes (i.e. dunes that are currently being shaped by the wind) backing wide sandy beaches. The beach-dune interface is less obvious north of the Salinas River and here the dunes are stable or accreting (Cooper, 1967). Pockets of recent dunes are also present in the Sand City to Monterey area. Areas landward of the dunes are dominated by lowlands, and seaward the beaches are bounded by a continental shelf which descends into the Monterey Submarine Canyon approximately 9-12 miles offshore (Figure 4). A second prominent offshore bathymetric feature is the ancient sediment lobe off the mouth of the Salinas River, which forms a bulge in the coastline (Figure 4).

Figure 4. Bathymetry of Southern Monterey Bay



Source: Douglas Smith (CSUMB)

Historically, the Salinas River flowed north along the coast behind the dune field and entered Monterey Bay north of present day Moss Landing Harbor. It may also have discharged near its present location, which is aligned with the ancient sediment lobe (Figure 4). In 1910, the river breached the dunes and was diked at its current location to prevent the river from flowing north into its old channel. In 1946, the U.S. Army Corps of Engineers (Corps) constructed two jetties and dredged an entrance channel at the present opening to Moss Landing Harbor. The historic opening to the north eventually silted in as a result of the reduction in flow.

1.3 INFRASTRUCTURE

1.3.1 Coastal Armoring and Development

Apart from short lengths of riprap and seawalls at Sand City and Monterey, the majority of the southern Monterey Bay shoreline is unarmored (Stamski et al., 2005a, b). Approximately 0.6 miles at the southern end (southern bight or Del Monte Beach, Figure 2) of the 16-mile shoreline is currently armored (less than 4%). Shoreline armoring is focused at the privately-owned oceanfront Monterey Beach Resort and Ocean Harbor House condominiums. At these sites the shoreline is fixed, and adjacent beaches and dunes continue to erode, causing armored areas to protrude seaward into the beach runup zones, and even the surf zone. This results in an adverse

effect by blocking lateral beach access and recreation, and can pose a public safety hazard (Figure 5, left panel). The armoring consists of 600 feet of seawall to protect Monterey Beach Resort and 700 feet of emergency riprap to protect the Ocean Harbor House condominiums. The riprap in front of the Ocean Harbor House condominiums (Figure 5, right panel) is due to be replaced with a permanent seawall within the footprint of the condominiums, and the seawall fronting the Monterey Beach Resort is due to be replaced with a new seawall abutting to the front of the present seawall.

Figure 5. Armoring at Monterey Beach Resort and Ocean Harbor House Condominiums

Monterey Beach Resort

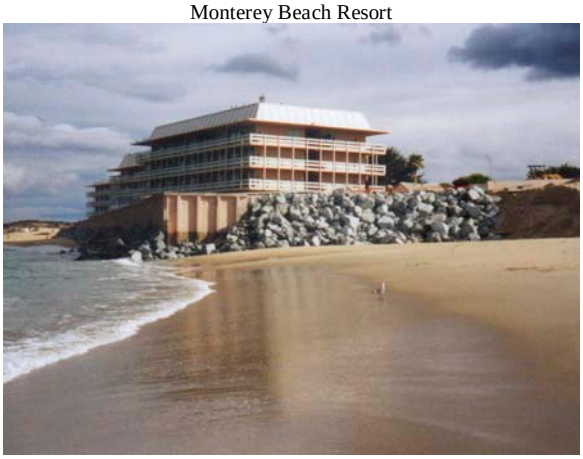


Photo taken: January 13, 2003 (Ed Thornton, NPS)

Ocean Harbor House condominiums

Photo taken: April 2006 (Gary Griggs, UCSC)

Shoreline armoring in the form of concrete and other debris is also present fronting the former sand mining complex at Sand City. Here, remnants of a cement mixing facility are located immediately north of Tioga Avenue (Figure 6). The facility is now used for temporary storage of construction equipment. Until at least 1990, concrete slurry was dumped here parallel to the shore to form an 800 foot-long concrete ridge that effectively acts as a seawall. In addition, at the seaward end of Tioga Avenue there is a 750 foot-long collection of debris and riprap, composed predominantly of un-engineered cement blocks, and the remains of a former road (Vista del Mar Street) where much of the asphalt has fallen over the bluff. A further 130 feet of riprap fronts the Del Monte Lake outfall (Figure 2). There is also a 470 foot-long concrete seawall in front of the main Monterey Bay Aquarium Research Institute (MBARI) building at Moss Landing.

Figure 6. Coastal Structures at Sand City

Collapsed former road at the end of Tioga Avenue

Photo taken: September 19, 2007 (Justin Vandever, PWA)

Concrete slurry 'wall'

Photo taken: September 19, 2007 (Justin Vandever, PWA)

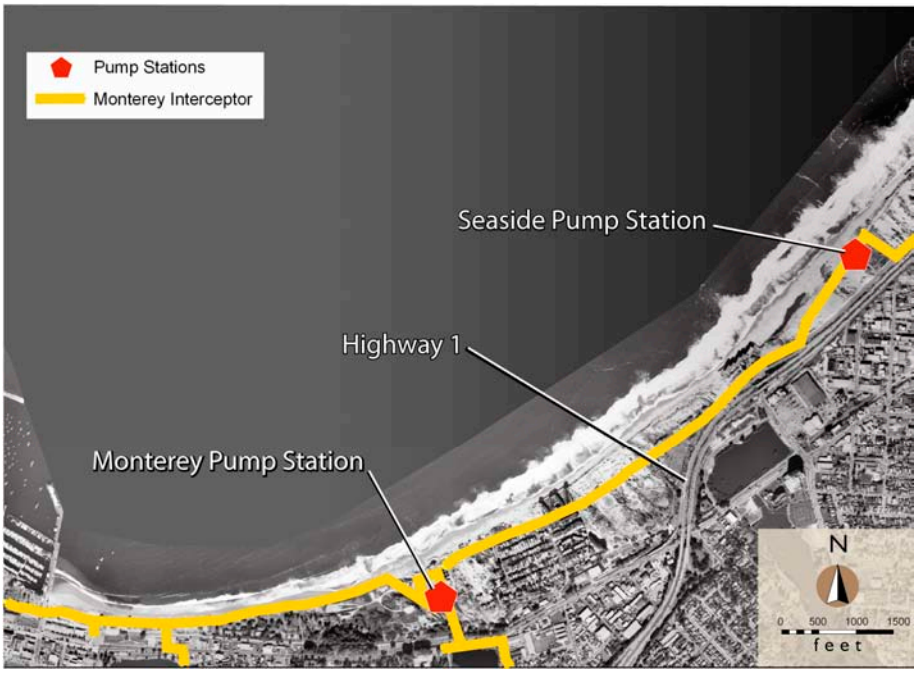
1.3.2 Utilities

Monterey Regional Water Pollution Control Agency (MRWPCA) pump stations, pipelines, and outfalls extend along the southern Monterey Bay shoreline from Marina to Wharf II (PWA and Griggs, 2004). Pump stations are surface or sub-surface structures housing wastewater pumps and pipeline connections. At the shoreline, pipelines are typically buried in the dunes or beneath the beach. The MRWPCA oceanfront facilities include (Figure 7):

- Monterey Interceptor pipeline extending from Seaside Pump Station to Wharf II. This pipeline is buried in the dunes between Seaside and Monterey Pump Stations and beneath the beach between Monterey Pump Station and Wharf II
- Seaside Pump Station which is set back about 100 feet from the present shoreline
- Monterey Pump Station which is set back about 350 feet from the present shoreline

The Monterey Interceptor pipeline was constructed between 1977 and 1981 to collect the raw wastewater from the cities of Pacific Grove, Monterey, Seaside, Sand City and Fort Ord for regional secondary treatment at the Marina sewage treatment plant before discharge into the ocean. The pipe ranges in diameter from 3.0 to 3.5 feet, and there are manholes approximately 500 feet apart along the pipe and at each point of connection. The manholes, in accordance with California Coastal Commission permit requirements, were set so that their tops were approximately four feet below the lowest 'normal' sand level on the beach. Several of the manholes are now sometimes exposed, and are at risk of damage due to erosion (PWA and Griggs, 2004).

Figure 7. Monterey Regional Water Pollution Control Agency Facilities and Highway 1



Source: Location of pipeline provided by Jennifer Gonzalez (MRWPCA)

1.3.3 Highway 1

Portions of Highway 1 curve seaward at Sand City and in the vicinity of Monterey Beach Resort (Figures 2 and 7). These sections of the highway may be threatened by coastal erosion in the future.

1.4 PHYSICAL PROCESSES

1.4.1 Tidal Regime

The southern Monterey Bay coast experiences mixed semidiurnal tides, with two high and two low tides of unequal height each day. The mean tidal range (defined as mean low water minus mean high water) at Monterey Harbor (Station ID: 9413450) is 3.5 feet and the diurnal range (defined as mean higher high water minus mean lower low water) is 5.3 feet (Table 1). Tidal range determines the extent of beach exposure and inundation throughout the tidal cycle. Particularly important are the timing and height of high tides coincident with maximum wave heights and surge developed during storms.

Table 1. NOAA Tidal Datums for Monterey Harbor (Station ID: 9413450)

	MLLW (feet)	NAVD 88 (feet)
Mean higher high water (MHHW)	5.34	5.48
Mean high water (MHW)	4.64	4.78
Mean tide level (MTL)	2.87	3.01
Mean sea level (MSL)	2.83	2.97
Mean low water (MLW)	1.10	1.24
Mean lower low water (MLLW)	0.0	0.14

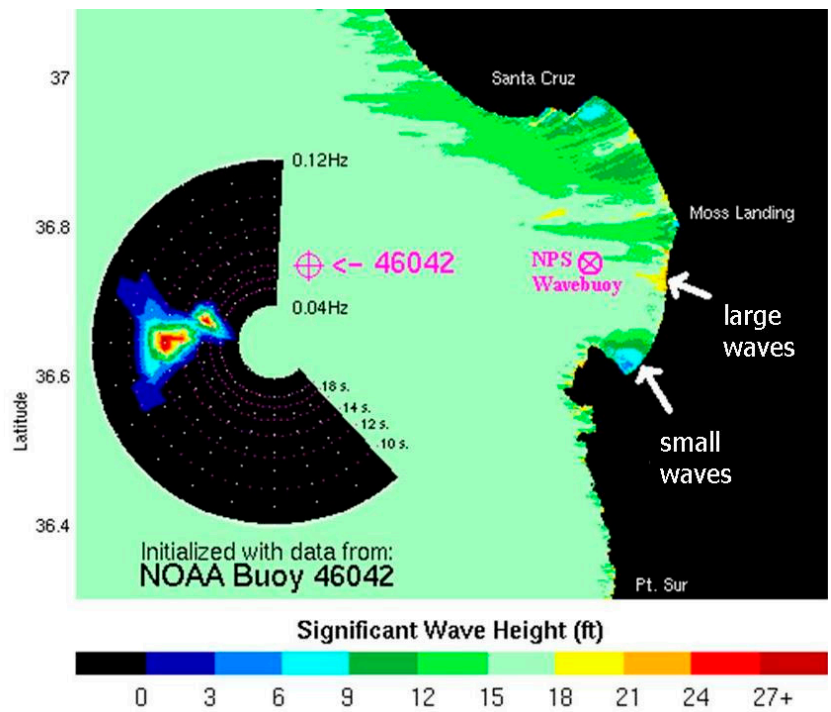
1.4.2 Wave Climate

With respect to sediment management, the wave climate of southern Monterey Bay is important for two reasons. First, differential wave energy alongshore causes variations in the magnitude of erosion due to wave impacts at the dune toe. Second, the direction and magnitude of wave approach relative to the shoreline orientation, controls the direction and strength of alongshore sediment transport.

The nearshore wave climate of southern Monterey Bay is impacted predominantly by waves from the northwest (Storlazzi and Wingfield, 2005). Xu (1999) reported a time series of wave height, period and energy data between 1990 and 1995 from a gauging station located 0.6 miles offshore from Marina. The time series showed that significant wave heights in winter are greater than in the summer and the highest waves arrive from the northwest in either season. Presently, the directional wave spectrum is measured every four hours at the NOAA wave directional buoy (Buoy ID: 46042) offshore of Monterey Bay and waves are refracted throughout the bay as part of the Coastal Data Information Program (CDIP). As a complement to this program, the wave height, direction, momentum flux and sediment transport have been calculated every 200 m (600 feet) alongshore in Monterey Bay since October 2007 (http://www.oc.nps.navy.mil/~thornton/cencoos) as part of the California Ocean Current Management Program (COCMP). Refraction occurs as the waves pass over Monterey Submarine Canyon focusing wave energy at Marina and Fort Ord and defocusing energy at Moss Landing. In addition, the shoreline of the southern bight is sheltered by Point Piños headland from waves from the south and west, resulting in reduced wave energy at

Monterey. The net result is a large alongshore energy gradient with relatively small wave heights at Monterey increasing to relatively large wave heights at Fort Ord and Marina (Figure 8) (Thornton et al., 2007).

Figure 8 Significant Wave Heights in Monterey Bay



Source: Coastal Data Information Program (http://cdip.ucsd.edu)

Longer term variations in wave climate are linked to large scale atmospheric variations, particularly El Niño-Southern Oscillation and Pacific Decadal Oscillation (PDO) events. El Niño events are characterized by above average rainfall and large waves generated by Pacific storms, and generally last between six and eighteen months. The two most energetic El Niño's of the past 50 years along the California coastline occurred in 1982-83 and 1997-98. The PDO is a 20-25 year climate oscillation based on sea surface temperature phases, which have implications for ecosystems, physical processes, and beaches (Revell and Griggs, 2006; Adams et al., 2007). The PDO controls the jet stream and storm tracks in the North Pacific, which affects wave direction. During negative phases (relatively low water temperatures), La Niña conditions are more prevalent (dominated by northwest waves), while during positive phases (relatively high water temperatures), El Niño conditions are more dominant (more westerly-directed waves). Higher intensity PDO and El Niño events were more common from 1910 to 1940, and after 1978, possibly continuing today, with the 1940 to 1978 period marked by a gentler climate.

The most destructive waves occur most commonly during El Niño events (Storlazzi and Griggs, 2000; Dingler and Reiss, 2002; Storlazzi and Wingfield, 2005) when storms increase in frequency and intensity, producing waves of exceptional height and period at the shoreline. El Niño winter storm waves tend to approach the Monterey Bay shoreline from the west or west-southwest, which diverge less due to refraction, resulting in larger waves at the shoreline than with storms from the northwest. Storlazzi and Griggs (2000) found significant correlations between El Niño events and the occurrence of large waves, higher than normal sea-surface elevations, and storms that caused significant erosion. A higher water surface together with the increased wave setup associated with the higher storm waves elevates the level of wave attack relative to the bluff toe. The timing of the El Niño storms also tends to be later in the winter season when the protective beach is already reduced, further exposing the bluff toe to wave attack. The 1982-83 and 1997-98 El Niño winter storms caused severe beach and dune erosion along central California's coast including southern Monterey Bay (Storlazzi and Griggs, 2000; Thornton et al., 2006).

1.4.3 Base Flood Elevations

The Federal Emergency Management Agency (FEMA) coastal flood studies in southern Monterey Bay (FEMA, 2007) projected the maximum elevations of wave runup and overtopping during a 100-year flood event, denoted by the Base Flood Elevation (BFE) (Table 2). Structures at elevations below the BFE may be subject to damages from direct wave impacts or undermining by wave scour. The BFE estimates do not include a future sea-level rise component.

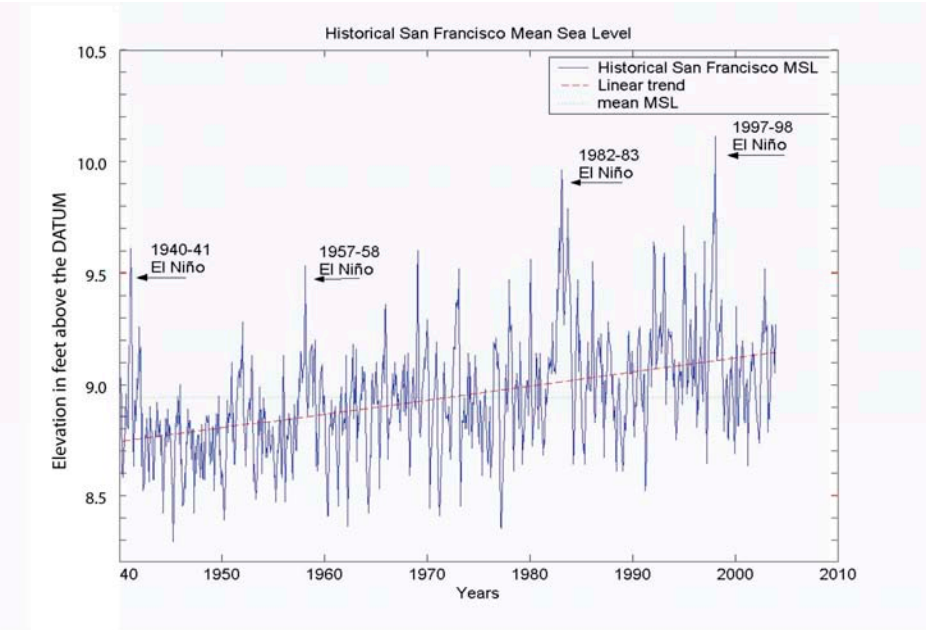
Table 2. FEMA (2007) Base Flood Elevations (BFE)

Location	BFE (feet NAVD)
North of the Salinas River mouth	23-24
Sand City (Tioga Avenue)	27
Seaside Pump Station	27
Monterey Beach Resort	24
North Del Monte Beach	26
Wharf II and South Del Monte Beach	22

1.4.4 Relative Sea-Level Rise

Measurements of monthly-averaged relative mean sea-level rise at Monterey started in 1973, providing only a short recent record for analysis. The Monterey record shows that relative sea-level has risen at a rate of 1.86 mm/year (0.31 ft/50 years) between 1973 and 1999. In order to determine if a longer record could be used to establish the long-term relative sea-level rise rate in southern Monterey Bay, the Monterey tide gauge data was compared to the San Francisco tide gauge data, which started in 1853 and is the longest continuous record in the U.S. The two time series have a high correlation coefficient (>0.9) with a slope of 0.77 at Monterey (Sesto, 2004) indicating that the San Francisco record can be used to infer relative sea level at Monterey since the regional land subsidence rates at these tide gauges is low (Battalio and Everts, 1989). The San Francisco record shows that relative sea-level has risen at a rate of 2.13 mm/year (0.35 ft/50 years) since 1906. The record shows significant annual variations, and spikes in mean sea level correlate with El Niño events (Battalio and Everts, 1989; Ryan et al., 1999) (Figure 9).

Figure 9. Historical Monthly Averaged MSL at San Francisco Relative to Station Datum



Source: Adapted from Sesto (2004)