COASTAL EROSION AND ARMORING IN SOUTHERN MONTEREY BAY

A Technical Report in support of the
Monterey Bay National Marine Sanctuary
Coastal Armoring Action Plan

Version 1.1

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Table of Contents

List of Figures

Note From the Author

This report is intended to be a living document that will be updated as relevant information is gathered through future working group meetings of the Monterey National Marine Sanctuary's (MBNMS) Coastal Armoring Action Plan. In particular, MBNMS staff may add additional data on the alternatives to mitigate coastal erosion and on the progress of specific armoring permits. It is also recommended that a section on management recommendations be included as these decisions are reached in the action plan process.

I would like to thank the following people for their scientific input and cooperation: Dr. Gary Griggs, Dr. Edward Thornton, Dr. Kiki Patsch, Dr. Douglas Smith, Dr. Cheryl Hapke, Mr. David Reid, and Mr. John Kasunich. In addition, I would like to thank Dr. Andrew DeVogelaere, Brad Damitz and Dr. Holly Price of the MBNMS for thoughtful review of this report.

I. INTRODUCTION

Development at the edge of California's highly erosive coast has led to increased pressure to protect both private and public infrastructure with various types of coastal protection structures, such as seawalls and revetments. The cumulative environmental impacts of this coastal armoring within the Monterey Bay National Marine Sanctuary (MBNMS; Figure 1.1) has been of growing concern, as they may interfere with the natural sediment dynamics, lead to the loss of public beaches, hinder public access to the coast, and have the potential to alter marine biological communities either during construction or via their long-term impacts (Stamski 2005).

In response to these concerns, the MBNMS is playing an increased role in the issue of coastal armoring as part of the congressionally-mandated update of its Management Plan. The sanctuary, in collaboration with other stakeholders, has developed an action plan with the goal of developing and implementing a proactive, regional approach to address coastal erosion and to minimize the negative impacts of coastal armoring on a sanctuary-wide basis.

As part of this action plan, the MBNMS has initiated a collaborative pilot effort with a number of partners to develop a regional planning approach that addresses the issue of coastal erosion and armoring in the southern Monterey Bay sub-region of the MBNMS, from the Salinas River mouth to Wharf #2 in Monterey. Participants in the Southern Monterey Bay Coastal Erosion and Armoring Workgroup include: representatives from the various local, state, and federal government agencies involved in studying and regulating these issues; scientific experts; and local decision makers.

The purpose of this report is to summarize scientific information on coastal erosion and armoring for southern Monterey Bay to support the sanctuary's Coastal Armoring Action Plan and the efforts of the Southern Monterey Bay Coastal Erosion and Armoring Workgroup as they consider effective ways to address this issue. This report provides background information on the geomorphic history of the area, summarizes the results of regional erosion studies, documents coastal development that may be threatened by erosion, and lays the groundwork for an investigation of alternatives to coastal armoring that are available in responding to coastal erosion.

a. Geologic Setting of Monterey Bay

Monterey Bay is a large, lowland coastal embayment, with rocky headlands at the north and south extremes and a sweeping arc of sandy, dominantly dune- and cliff-backed shoreline in between (Figure 1.2). The submarine Monterey Canyon is the most prominent feature of the Bay; the main canyon and its tributaries provide bathymetric extremes in which geology and oceanography coalesce to shape the seafloor as well as the adjoining coast. Two main rivers drain into the bay, the Pajaro and the Salinas, located to the north and south, respectively, of a major estuary, Elkhorn Slough, which is situated just landward of the head of Monterey Canyon. Prior to the last glacial maximum, 18,000 years ago, vast areas of the broad continental shelf were exposed, on which dune fields formed as sand from coastal rivers was transported inland by prevailing onshore winds. For the past 18,000 years, sea level has been steadily rising, eroding those dune fields at an average rate of approximately 0.7 meters per year (m/yr) (Smith et al. 2005; Thornton et al. in press). The more resistant, rocky headlands at Santa

Cruz and Monterey have eroded significantly slower, and this gradient in erosion has sculpted the arcuate Monterey Bay.

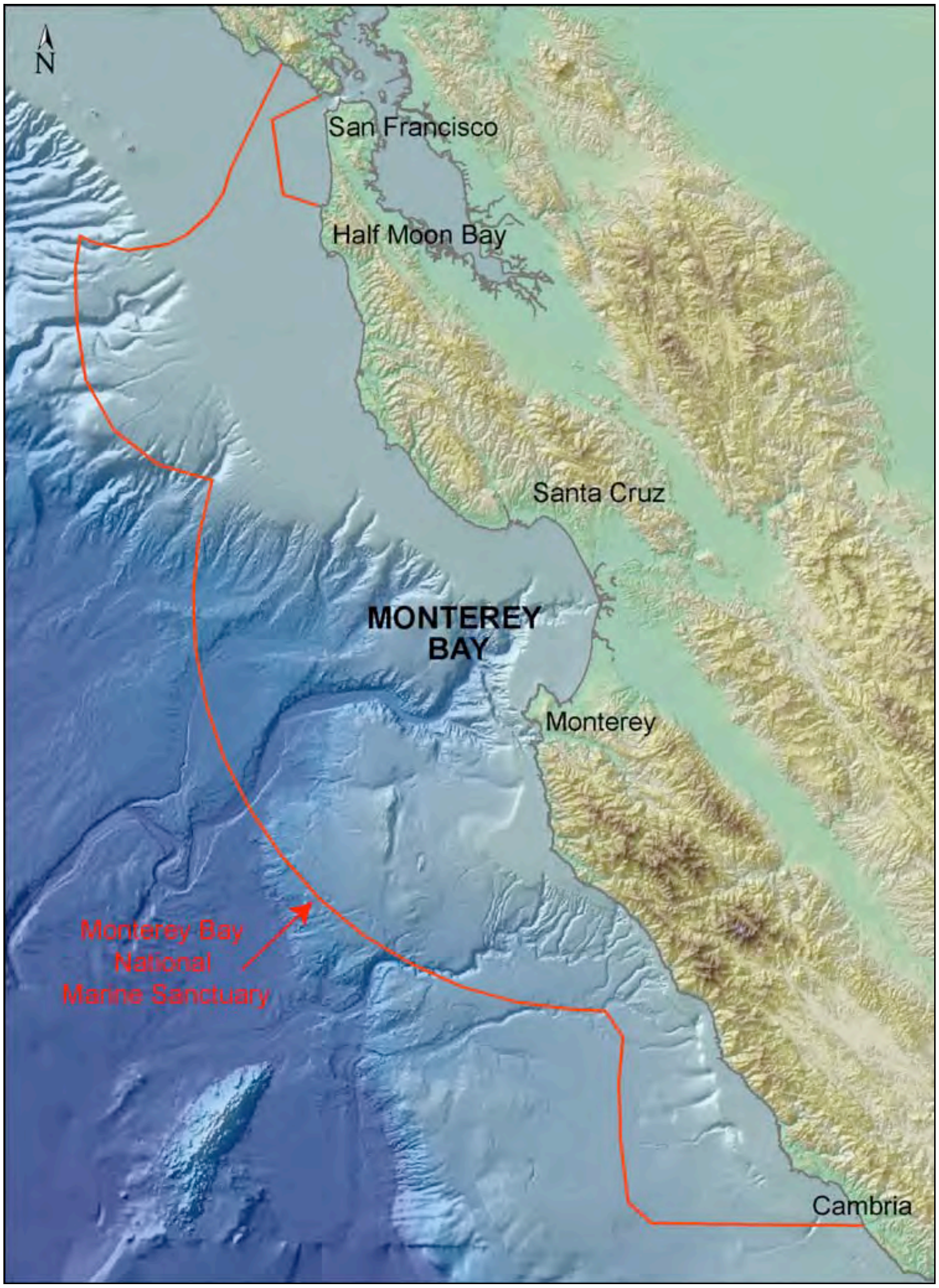

Figure 1.1: Map of the Monterey Bay National Marine Sanctuary (outlined in red).

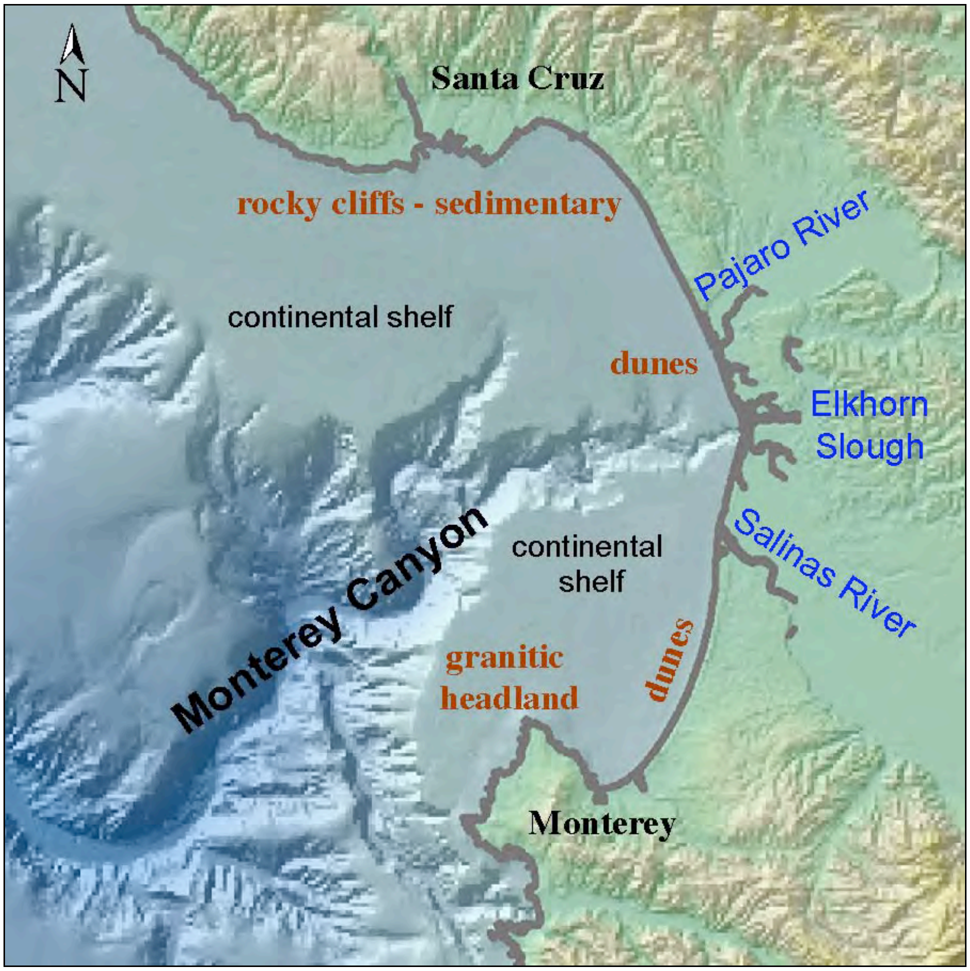

Figure 1.2: Map of Monterey Bay region with major geomorphic features labeled.

b. Monterey Bay Littoral Cells

Monterey Canyon effectively bisects the bay, dividing the region into two major littoral cells (Figure 1.3). A littoral cell is a self-contained compartment of the coast, which includes all sources and sinks for littoral, or beach-sized, sand. In Monterey Bay, sources of beach sand include discharge from coastal rivers and erosion of coastal bluffs; natural sinks or losses can occur where submarine canyons intersect the nearshore zone, where wind transports sand from beaches into coastal dunes, or where sand gets dispersed offshore onto the continental shelf. Littoral drift is driven by longshore currents, which

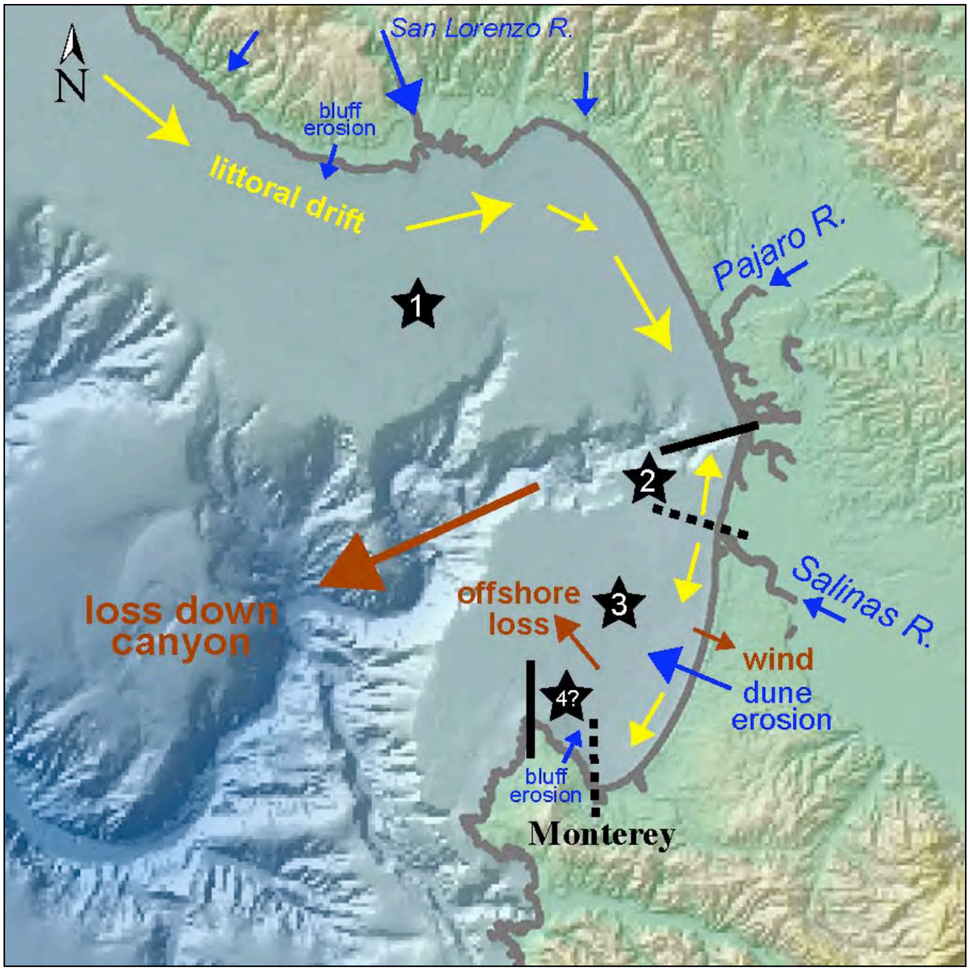

Figure 1.3: Schematic map of Monterey Bay littoral cells. Black bars represent divisions between littoral cells, which are highlighted with stars. Dashed divisions are not as fully constrained as solid divisions. Blue arrows represent major inputs of sand to the system, brown arrows represent significant losses of sand from the system, and yellow arrows represent the approximate path of littoral drift. Arrows are not to scale.

move sand from sources down the coast like a river within the nearshore zone; the direction of this movement is dictated by the incident angle of the dominant wave patterns. In theory, there is no transfer of sand between adjacent cells. Understanding the boundaries of these cells is therefore vital to managing coastal resources because activities that interrupt sand movement in one portion of a cell can impact areas down-coast within the same cell.

Every year, approximately 230,000 m^3 of sand travels from beach to beach along northern Monterey Bay, driven in a southerly direction by the dominant northwest waves (Griggs and Johnson 1975) (Littoral cell #1 on Figure 1.3). This is equivalent to 23,000 dump truck loads of sand annually moving down the coast. That sand gets channeled offshore when it reaches the canyon and is removed from the littoral system. In southern Monterey Bay, the definitive boundaries of littoral cells and rates of transport are not well documented. It is generally agreed upon that there are at least two sub-cells in this region: a small cell in which sand is transported from the Salinas River north into the canyon (#2 on Figure 1.3); and a larger cell that extends from the Salinas River south towards the Monterey granitic headland (Dorman 1968; Arnal et al. 1973; Griggs and Jones 1985; Thornton et al. in press) (#3 on Figure 1.3).

Sources of sand in southern Monterey Bay are the Salinas River, though this is thought to contribute a minor amount of sand-sized material, and erosion of coastal dunes. Unlike northern Monterey Bay, lateral transport of sediment appears to be minimal in this region, as evidenced by the lack of sand build-up against the north side of Wharf #2 (PWA 2004; Thornton 2004). Rip currents are likely the dominant sand transport mechanism in southern Monterey Bay, moving sand predominantly offshore instead of laterally down the coast (Smith et al. 2005; Thornton et al. in press). Potential sand sinks in the system include losses into Monterey Canyon, offshore transport onto the continental shelf, sand mining, and removal by wind onto adjacent dunes. The focus of this report is on the larger of these southern Monterey Bay (SMB) cells, from the Salinas River to the southern end of Del Monte Beach (#3 on Figure 1.3).

An additional sub-cell may exist between the Monterey Harbor (at the end of Del Monte Beach) and Point Pinos, the northernmost tip of the Monterey peninsula (#4 on Figure 1.3) (Thornton 2004). Lines of evidence that support division of the littoral cell at this location include drastic differences in lithology, coastal orientation, and beach mineralogy. The northeast-facing peninsula is composed of resistant granite that receives muted wave energy, while the northwest-facing inner bay coastline is made up of unconsolidated dunes that are routinely pounded by intense wave action. Together, these two factors indicate that the processes and rates of erosion are not comparable between the peninsula and the inner bay and may necessitate separate analyses. In addition, beaches on the peninsula are composed dominantly of granitic materials (*e.g.*, coarse-grained, angular potassium and sodium-rich feldspar, quartz, mica, amphibole, etc.), yet beaches to the north of the harbor are made up of grains that originated from erosion of southern Monterey Bay dunes (*e.g.*, finer-grained, rounded quartz and sedimentary lithic fragments). This distinction in beach mineralogy suggests that littoral drift is not transferring eroded dune sand to the peninsula and therefore, there may be a subdivision in the overall littoral cell at this point (as drawn on Figure 1.3).

c. Geomorphology of Coastal Landforms

The shoreline of SMB is an 18 km stretch of continuous sandy beach, being wider at the southern end than at the northern end (Figure 1.4). The morphology of beaches in this region varies from season to season, but they are generally wider and gently sloping in summer and narrower and steeper in winter. The dunes at the back edge of the beach have an average height of 10.3 m, but can be as high as 46 m (Thornton et al. in press)

(Figure 1.5). Most of the dune surfaces that are not directly exposed to wave energy are vegetated, indicating that the dunes are stabilized in some areas. Yet, drifting sand across Highway 1 is evidence of some inland dune migration because of prevailing onshore winds (Figure 1.6). Erosion of these dunes, which has been occurring since sea level began to rise at the end of the last glacial period, is the dominant sand supply to the SMB littoral cell (Figure 1.3).

Figure 1.4: Relative beach width (green text) and adjacent dune morphology (brown text) in southern Monterey Bay. Distances from Wharf #2 in Monterey are shown in kilometers (black triangles). Coastline descriptions from Coyne (2001).

Figure 1.5: Aerial photograph of wave-cut dunes near the relatively undeveloped area of Fort Ord, California. This type of erosion provides much of the sand for the southern Monterey Bay littoral system. Despite the fact that this photograph was taken in summer, the beach is relatively narrow. During storms and/or high tides, waves wash up the beach and undercut the dunes. See Figure 1.4 for location of Fort Ord. Photograph copyright © 2002 Kenneth & Gabrielle Adelman (http://www.californiacoastline.org/).

Figure 1.6: Aerial photograph of the Monterey Beach Hotel (Seaside, CA) in summer, showing a wide beach, low back-beach area, and migrating dunes. In contrast to Figure 1.5, there is significant development along this stretch of southern Monterey Bay. See map Figure 1.4 for location of the hotel. Photograph copyright © 2002 Kenneth & Gabrielle Adelman (http://www.californiacoastline.org/).

d. Wave Climate

Differences in erosion of coastal landforms along SMB appear to be dependent upon the amount of wave energy reaching the coast and how that energy is related to tides. The most dominant wave pattern affecting SMB is from Northern Hemisphere Swell; the resultant northwesterly wave trains refract over Monterey Canyon and impact the central part of the bay most intensely (Figure 1.7). Northern Hemisphere Swell is most prominent from October to May. Southern Hemisphere Swell, which produces smaller waves than its northern counterpart, is most prevalent in summer. The southern part of SMB receives less direct wave energy than the central section of the bay because it is partially protected from southerly waves by the Monterey Peninsula and because northwesterly waves have dissipated slightly compared to when they hit the central bay coast. Local swell can also arise from regional low-pressure systems (Storlazzi and Griggs 2000). Overall, the destructive force of waves is greatest when high tides and strong storm waves are coincident, a situation that commonly occurs during El Niño events (Storlazzi and Griggs 2000; Dingler and Reiss 2002).

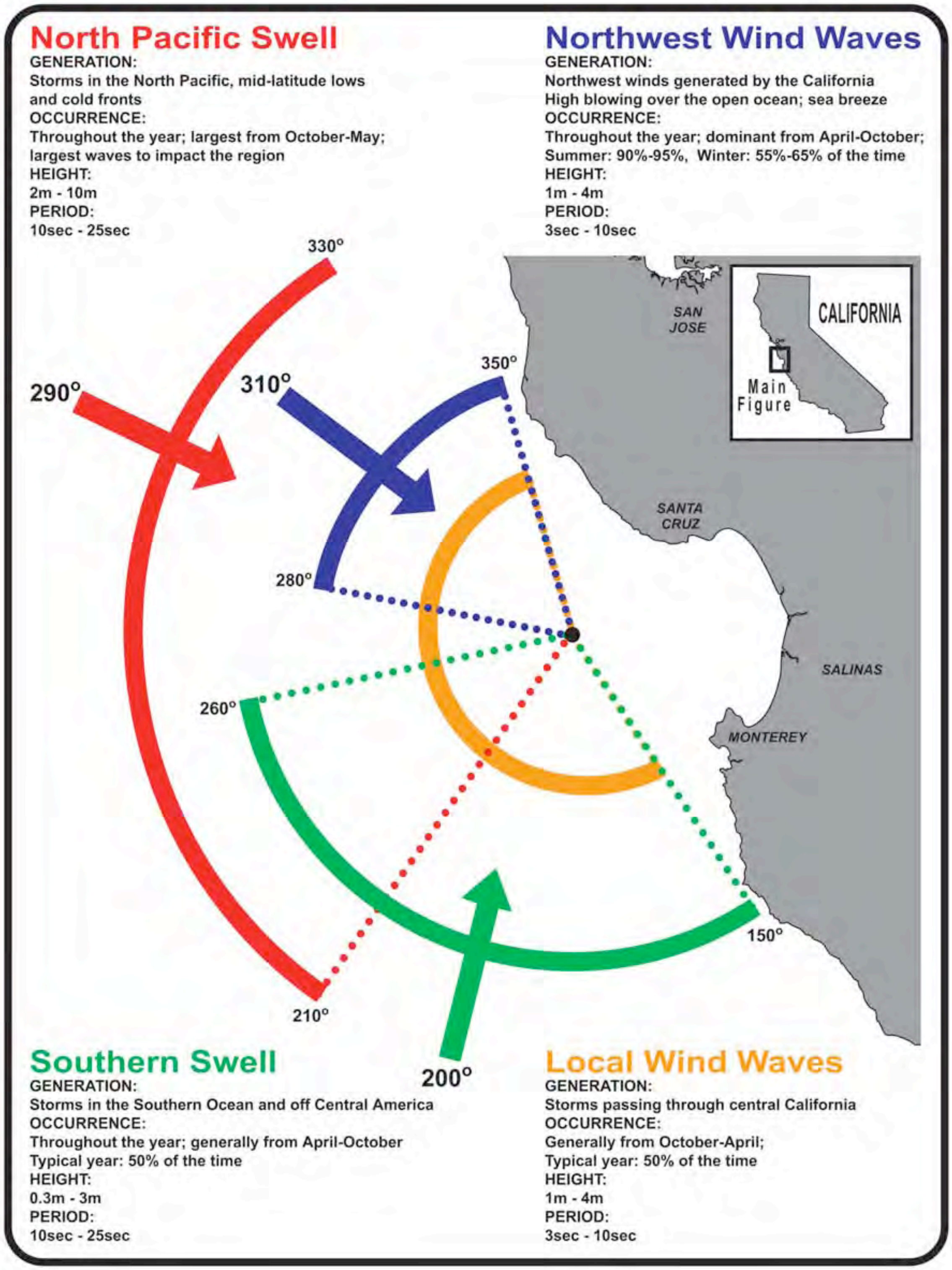

Figure 1.7: Major wave patterns impacting the Monterey Bay. This compilation was generated by analyzing almost ten years of hourly buoy data on wave height, period and direction, as well as wind speed and direction (Storlazzi and Wingfield 2005).

e. Erosion and Sand Supply in Southern Monterey Bay (SMB)

The interaction of waves with the shoreline of SMB serves to shape beaches and sculpt coastal dunes. Prevailing onshore winds prevent the seaward migration of dunes in this region; the main forcing on their development is wave erosion. The erosion of dunes by waves occurs more often in winter months, when beaches are narrow and storms are stronger and more frequent. Erosion in this region is highly episodic, occurring in steps when high tides coincide with large, storm-generated waves (Dingler and Reiss 2002). At these times, swash climbs up the beach and undercuts the base of the dune, causing the overlying sand to slump onto the beach where it is washed out with retreating waves and moved into the littoral system (McGee 1987).

A significant, but generally historical, human-induced change to the coastal environment in SMB has been the mining of sand from beaches and dunes. Exporting sand is a form of primary erosion and can potentially induce secondary erosion by reducing the sand supply to beaches down-coast in the littoral cell. Less sand moving along the coast can decrease beach widths, which allows waves to more readily attack back-beach dunes and erode the coast. In this manner, the removal of sand from the surf zone is the most important type of mining in relation to sand budgets. Sand that is within back-beach dunes has already been effectively taken out of the littoral system; therefore mining dune sand would have less of an impact on the littoral cell (Thornton et al. in press).

The sand in this region is of superior quality for numerous industrial uses, such as the manufacture of abrasives and stucco, and for water filtration (Griggs et al. in press). Mining started as early as 1906, with up to six different plants between Marina and

Seaside by 1972; these mining companies operated unregulated until 1968 when leases were issued and managed by the State Land Commission. The Army Corps of Engineers put additional regulations in place in 1974. Leases on all mining operations expired in the late 1980's and all mining of the surf zone was supposedly discontinued as of 1990. Mining of dune sand is still underway in Marina (Figure 1.8). While the current mining in Marina is not technically considered to be a loss of sand from the littoral system, questions have arisen as to whether the methods being employed there are extracting valuable beach sand. The operations of this plant should be investigated to further to ensure that they are collecting only dune sand that has no natural means for returning to the littoral system.

Figure 1.8: Sand mining operations in northern Marina, California. The company has dredged a lagoon from which they extract sand. Some argue that the lagoon actually traps beach material in addition to dune sand. See Figure 1.9 for location of mine. Aerial photograph taken in October 2004; copyright © 2002 Kenneth & Gabrielle Adelman (http://www.californiacoastline.org/).

Damming of coastal rivers is another anthropogenic mechanism by which sediment supply to the beach can be reduced, thereby exacerbating erosion of back-beach features. As hillsides in a watershed erode, fine sediment is carried down rivers in suspension and larger grains are transported by bouncing along the river bottom (referred to as bedload). In general, the stronger the flow of a river, the more sediment it can carry and the larger the grain size it can transport. When dams are placed on coastal rivers, the bedload gets trapped behind the dam, building up in the reservoir over time, instead of being carried out to the littoral system.

Beaches in this region are composed dominantly of medium-grained sand and, in northern Monterey Bay, rivers provide 75-90% of that littoral material (Best and Griggs 1991). In contrast, clay and silt particles that reach the coast are generally resuspended by wave action and carried offshore. Thus, when dams block bedload transport, only fine-grained sediment makes it down the river, which does not support beach development. Sand supply reduction from coastal dams is an issue for the health of many littoral cells along the California coast and removing dams could be an option for erosion management (Willis and Griggs 2003).

The impact of coastal dams is not always straightforward, and may warrant a case-by-case analysis. For example, a recent study found that there was a 33% reduction in the amount of sand reaching the SMB littoral system because of dams on the Salinas River (Willis and Griggs 2003). Yet, as the gradient of the Salinas River has lowered over the past several thousand years, its contribution of sand to the SMB littoral system has decreased naturally. Sand-sized material is transported down the gentle slopes of the lower Salinas River only during the heaviest storms, and much of that sand will get deposited on the wide flood plain adjacent to the channel instead of being carried out to the coastal zone. Therefore, while a 33% reduction in Salinas sand supply seems considerable, the impact on SMB beaches may not be significant (Thornton et al. in press). In this case, erosion of coastal dunes, not river runoff, appears to be the major contributor of sand to the SMB littoral cell.

f. Land Use and Coastal Protection Structures

The coastal zone in SMB is relatively undeveloped, which is consistent with the inherent hazards of building in dynamic beach and dune environments (Figure 1.9). Many kilometers of the sandy shoreline and back-beach area are protected as state parks, including Marina State Beach, the new Fort Ord Dunes State Park, and Monterey State Beach. These long stretches are used primarily for recreation, including hiking, hang-gliding and picnicking; strong rip currents make swimming and surfing hazardous.

At present, there are a handful of structures built in the coastal zone that are being threatened by wave attack. These developments include a 196-room hotel built directly on the beach, a 172-unit condominium complex built on coastal dunes, and various drainage and sewer outfall pipes, each of which will be discussed in detail later in this report. Most of this construction took place in the 1960's and 1970's, a relatively quiet La Niña period, with few major storms. The ensuing El Niño events of the 1980's and 1990's caused extreme and unpredicted erosion, with several meters of coastal retreat at some isolated locations over the course of one winter (Griggs et al. in press). In response to these storms, owners of coastal developments and infrastructure were forced to place protective structures, or armoring, in front of their property to block wave energy and

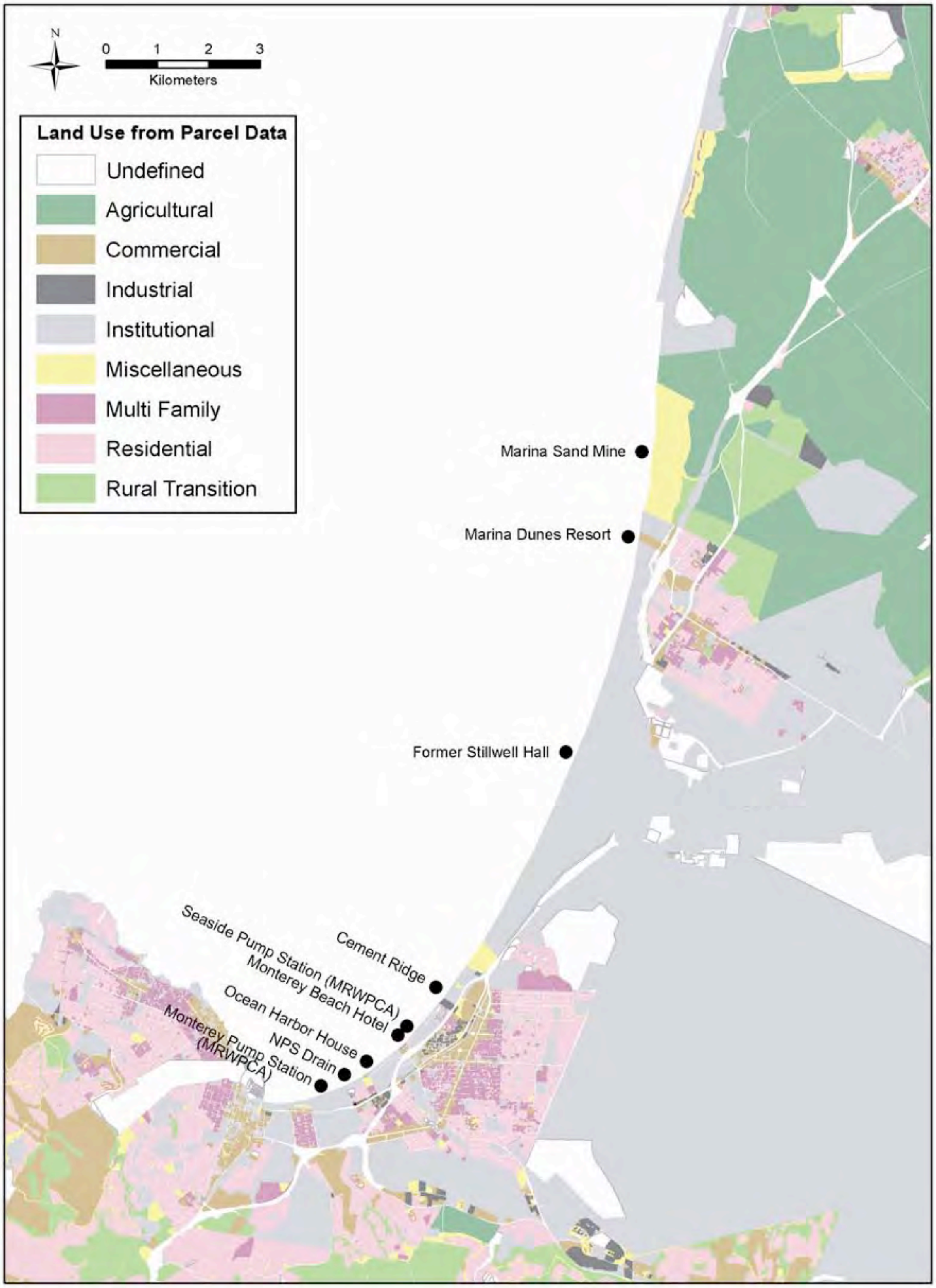

Figure 1.9: Generalized land use in southern Monterey Bay, adapted from Monterey County parcel data. Coastal development features, discussed in later in this report, are also highlighted.

slow down or halt erosion. Approximately 1 km between the Monterey Harbor and the mouth of the Salinas River is currently armored (Thornton et al. in press). Armoring of the shoreline, particularly in an area with high erosion rates, is an expensive and, quite often, an ultimately unsuccessful effort. The potential impacts of that armoring are discussed in a National Marine Sanctuaries Conservation Series Report entitled, "The Impacts of Coastal Protection Structures in California's Monterey Bay National Marine Sanctuary," which can be downloaded at: http://sanctuaries.nos.noaa.gov/special/con_coast/coast_study.html (Stamski 2005).

The population is growing in the southern Monterey Bay region, as is the desire to live and work on the coast. Creation of a comprehensive coastal erosion plan will be crucial in exploring options to manage coastal erosion beyond traditional armoring techniques, and in developing a system for improving coordination among agencies and jurisdictions involved in the permitting of coastal armoring structures. A long-term plan will also be essential in predicting when and where structures will be threatened by wave attack, and can be used to identify hazardous areas where construction should be regulated to promote sustainable development. The purpose of this report is to provide scientific background information on coastal erosion and armoring for southern Monterey Bay in support of the sanctuary's Coastal Armoring Action Plan and the efforts of the Southern Monterey Bay Coastal Erosion and Armoring Workgroup.

II. COASTAL EROSION DATA

a. Erosion Rates

The most common method of assessing coastal erosion is to determine an erosion rate, which is generally the amount of linear coastal retreat (perpendicular to shore) that has taken place over a given period of time. These rates are essential for establishing coastal land use planning measures, such as setbacks. Yet, obtaining site-specific erosion rates is not a trivial task. One of the most robust methods for calculating erosion rates is to digitally compare historical aerial photographs (a technique referred to as stereo-photogrammetry). A comparable shoreline feature is digitized on each set of photographs and the difference between them, divided by the number of years spanning between the photographs, yields the erosion rate (reported as a unit length per unit time (e.g., meters per year (m/yr)). There are many ways to analyze aerial photography, which involve differing degrees of accuracy and precision that should be quantified.

More emergent techniques include the use of LIDAR (LIght Detection And Ranging), a method using airborne scanning laser surveying, and GPS (Global Positioning System) surveys, which determines coastal positions from satellites (see Smith et al. (2005) for a more detailed discussion of these techniques). These data sets can be expensive and historical photographs may not be available. In addition, a substantial amount of training is often necessary to correctly analyze and interpret the data with scientifically reproducible results.

Controversy in coastal planning can arise because different, yet valid, erosion rates can be calculated for a single stretch of coast. The key factor in these discrepancies is usually the time interval over which the analysis was made. For example, Geologist A calculated a retreat rate of 0.2 meters per year (m/yr) by comparing aerial photographs from 1965 and 1975. Geologist B used aerial photographs from 1980 to 1990 and calculated a rate of 1.5 m/yr. Both geologists calculated erosion rates with the same, reproducible method over a period of ten years; yet, because the time interval used by Geologist B included one of the most severe El Niño events in recent history, his/her erosion rate is much higher.

In the example above, a 50-year setback distance would be 10 meters for Geologist A and 75 meters for Geologist B. Given the exorbitant costs and low availability of coastal parcels, this discrepancy could dictate where, and even if, a building is constructed. Thus, it is imperative that a representative time interval is assessed in erosion rate calculations to derive long-term average retreat. Yet, even with a long-term rate, the episodic and somewhat unpredictable nature of coastal erosion suggests that erosion rates should only be used as guidelines in coastal planning, not as irrefutable facts.

In a recent consulting report produced for the Monterey Regional Water Pollution Control Agency (MRWPCA) by Philip Williams and Associates, Ltd. (PWA), a distinction was made between *short-term* or *event-based* erosion versus *long-term* erosion (PWA 2004). Short-term erosion occurs in a single event or series of events (e.g., an El Niño winter), the mechanisms of which include not only direct wave impact, but also flooding, undermining by scour, and removal of overburden (in the case of buried pipelines). Long-term erosion was defined by PWA as the, "landward migration of the shoreline over the 50-year planning horizon." The difference between the short and long term rates was drastic. For example, over the 1997-98 El Niño winter, an erosion rate of 13.0 meters/year (42.6 feet/year), was reported at Fort Ord, compared to a long-term rate of 1.1 meters/year (3.6 ft/yr). Erosion rates utilized by PWA were derived predominantly from work of L. A. Egley (short-term rates) and J. Conforto Sesto (long-term rates), both graduate students at the Naval Postgraduate School (NPS); Dr. Edward Thornton of NPS has compiled these studies with others in a comprehensive manuscript that will be described in detail later in this report.

Using these two types of rates, PWA classified the risk of a series of MRWPCA facilities. High risk facilities were those that: 1) would be located within the zone that could be significantly impacted by short-term (or event-driven) erosion; or, 2) would be located seaward of the predicted 50-year shoreline, as determined via long-term erosion rates. This report was able to assess risk for important infrastructure relative to erosion that occurs on both the short and long term, a methodology that could be valuable for MBNMS coastal plans.

Studies of coastal retreat in southern Monterey Bay, such as the Philip Williams and Associates report described above, are a testament to this potential variability in erosion rates. The analyses described herein have different scopes and degrees of scientific accuracy, and were carried out by: the University of California at Santa Cruz (UCSC), California State University in Monterey Bay (CSUMB), the Naval Postgraduate School (NPS), the Untied States Geological Survey (USGS), and Haro, Kasunich and Associates, Inc. At this point in time, the researchers who completed these studies are the key points of contact for questions on regional erosion (see Appendix 1). An assessment of all the available data is intended to assist sanctuary planners in understanding how erosion changes along this sandy stretch of coast.

b. Living with the Changing California Coast

In 1985, Dr. Gary Griggs, professor of Earth Sciences at UCSC, and others published a book entitled, *Living with the California Coast*, an exhaustive compilation of hazards and resources for the state's entire shoreline (Griggs and Savoy 1985). An updated edition, *Living with the Changing California Coast*, will be published in 2005, including a set of maps depicting coastline geomorphology, erosion rates, and relative hazard zones along the coast (Griggs et al. in press). The book is intended to be a descriptive guide for the public; yet the data on erosion and the historical narratives are a valuable resource for regional planners as well.

Local experts provided information to establish hazard zones and contributed detailed descriptions of geology, oceanography and development history in each coastal region. The erosion rates were collected from a wide variety of technical consulting reports and scientific studies; these rates have been partially updated since the 1985 edition. From a regional analysis perspective, it is difficult to compare the various retreat data because many methods and time periods were utilized to calculate the rates. Yet, the rates and hazard zones documented in *Living with the Changing California Coast* provide important overall trends for shoreline change.

Just south of the mouth of the Salinas River mouth, retreat rates were reported at 41 centimeters per year (cm/yr) (1.3 feet per year (ft/yr)) and 86 cm/yr (2.8 ft/yr) (Figure 2.1). Low, active dunes and a lagoon, formed by the Salinas River, back this area (Figure

1.4). Further south at Marina State Beach, near the end of Reservation Road, erosion increase dramatically, with rates of 163 and 155 cm/yr documented (5.3 and 5.1 ft/yr, respectively). A low, narrow strip of active dunes is situated immediately adjacent to Marina State Beach, with older and higher dunes further inland. The stretch from the mouth of the Salinas River to approximately the southern end of Marina State Beach was deemed a "moderate risk" area for coastal hazards.

A 9-km long "high risk" hazard zone begins at the north end of Indian Head Beach and extends south to approximately Ocean Harbor House condominiums, as demarcated by the *Living with the Changing California Coast* authors. This region is classified as hazardous because the coast receives the most direct, intense wave energy at that location, the beach is relatively narrow and the high, unconsolidated dunes are easily eroded. This is reflected in the extreme erosion rates reported for this region. In proximity to the former Stillwell Hall site (Fort Ord), an erosion rate of 244 cm/yr was recorded (8.0 ft/yr). Further south, at the beaches of Sand City, slightly slower rates of 122 and 188 cm/yr (4.0 and 6.2 ft/yr, respectively) are recorded. The backshore in this section is composed of active dunes and, in general, the beach is slightly wider than the beach at Fort Ord. A more moderate rate of 61 cm/yr (2.0 ft/yr) was calculated near the Monterey Beach Hotel seawall.

Approximately halfway down Del Monte Beach, the *Living with the Changing California Coast* hazard level drops from high risk to moderate risk, just southwest of the Ocean Harbor House condominiums. From this point to the Monterey Harbor north breakwater, the beaches are slightly wider than those in the more hazardous zone to the north and the backshore area consists of lower dunes (Figure 1.4). The lowered hazard status is reflected in lower erosion rates as well, with rates of 28 to 30 cm/yr (0.92 to 0.98 ft/yr, respectively) near Monterey State Beach, just east of the breakwater.

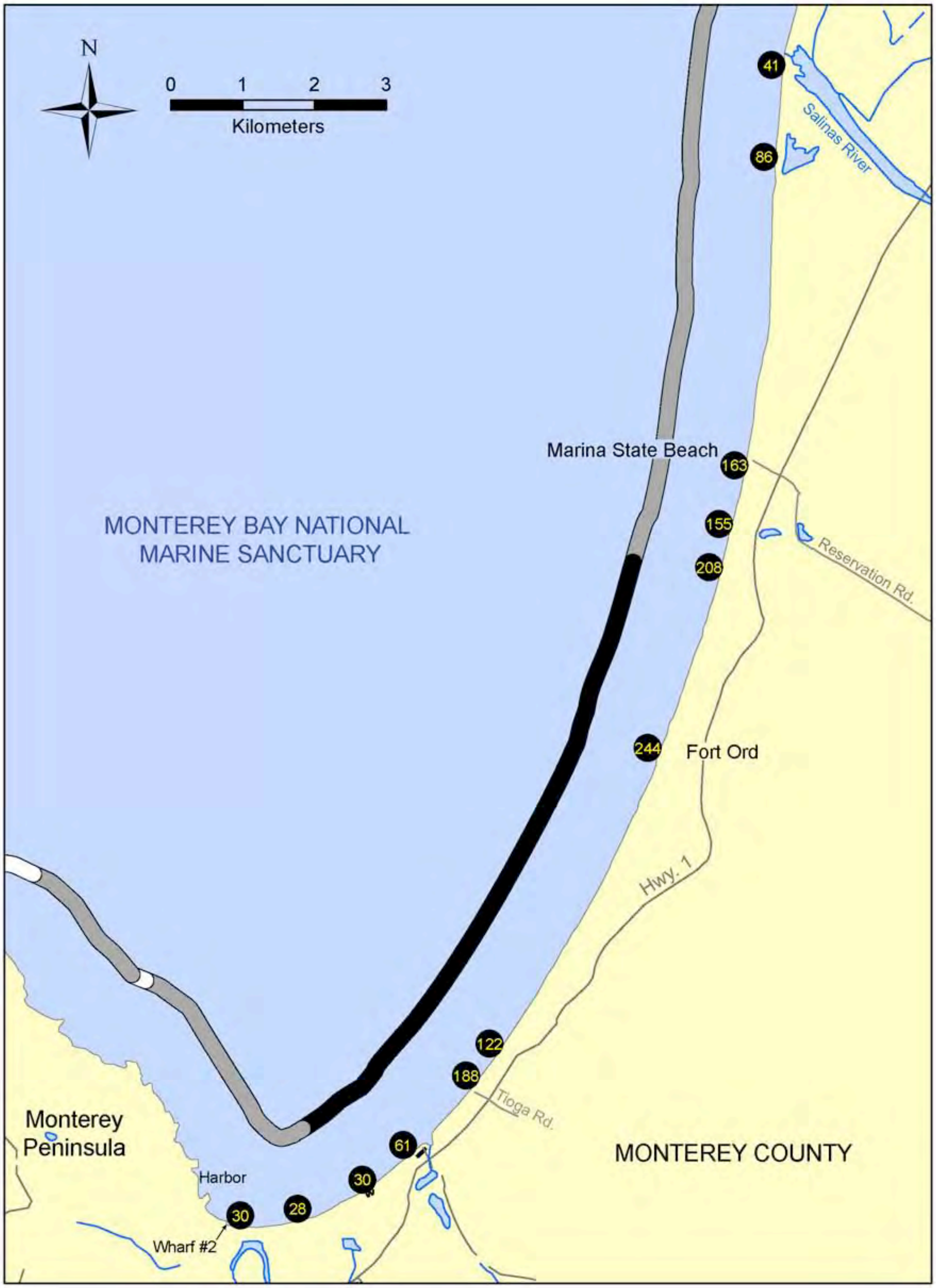

Figure 2.1: Coastal erosion rates, reported in centimeters per year (black circles), and relative hazard zones (black=high risk, grey=moderate risk, white=low risk) as documented in *Living with the Changing California Coast* (Griggs et al. in press). For reference, 100 cm = 3.28 ft.

c. Southern Monterey Bay Critical Erosion Sites (CSUMB study)

A recent study from the California State University, Monterey Bay (CSUMB), utilized a combination of historical aerial photographs and GPS surveys to assess erosion at four armored, or historically-armored, stretches of the SMB coast (Gref 2005). The research was completed as part of an undergraduate senior capstone project and, as of the completion of this report, has yet to be peer-reviewed for a scientific journal. Dr. Douglas Smith, professor of Earth System Science and Policy at CSUMB, supervised the project. The data are included here because of their relevance; Smith et al. (2005) provide a robust discussion of the methodology and results for this analysis as well.

Gref digitized the coastline on historical aerial photographs from 1976, 1986 and 2001; the intersection of the cliff or dune with the active beach was chosen to represent the coastline. In 2004, this datum was mapped via GPS surveys. The four years of data were digitally compared and erosion rates were determined as the amount of coastal retreat from 1976 to 2004, along transects across the beach, perpendicular to the shoreline (shore-normal). An average rate was then calculated for each site from the various transects.

For Marina State Beach, at the end of Reservation Road, Gref calculated rates along 10 shore-normal transects and found a total retreat rate of 150 cm/yr (4.9 ft/yr) (Figure 2.2). Near the former Stilwell Hall site, on Fort Ord coastal property, 14 transects were averaged to yield an erosion rate of 200 cm/yr (6.6 ft/yr). Erosion across 14 transects for the 4 years of measurements was 160 cm/yr (5.2 ft/yr) near the Monterey Beach Hotel in Seaside. Rates were calculated for the areas adjacent to, not in front of, the hotel's seawall, because the seawall has fixed the coastline since 1968. Finally, Gref determined erosion rates along 6 transects in front of, and adjacent to, the Ocean Harbor House condominiums, calculating an average retreat rate of 70 cm/yr (2.3 ft/yr). Riprap placed in front of the condominiums since 1984 has slowed erosion; therefore natural coastline retreat rates at this site may actually be greater than 0.7 m/yr.

The rates calculated by Gref support the general patterns documented by other researchers. Erosion has been most severe at Fort Ord, with Marina State Beach and Monterey State Beach having slightly less retreat. Yet across the region, coastal erosion creates hazardous conditions, with average rates from 2.3 to 6.6 feet per year. The role of coastal protection structures (armoring) is very important in the areas highlighted by Gref and will be discussed in detail later in this report.

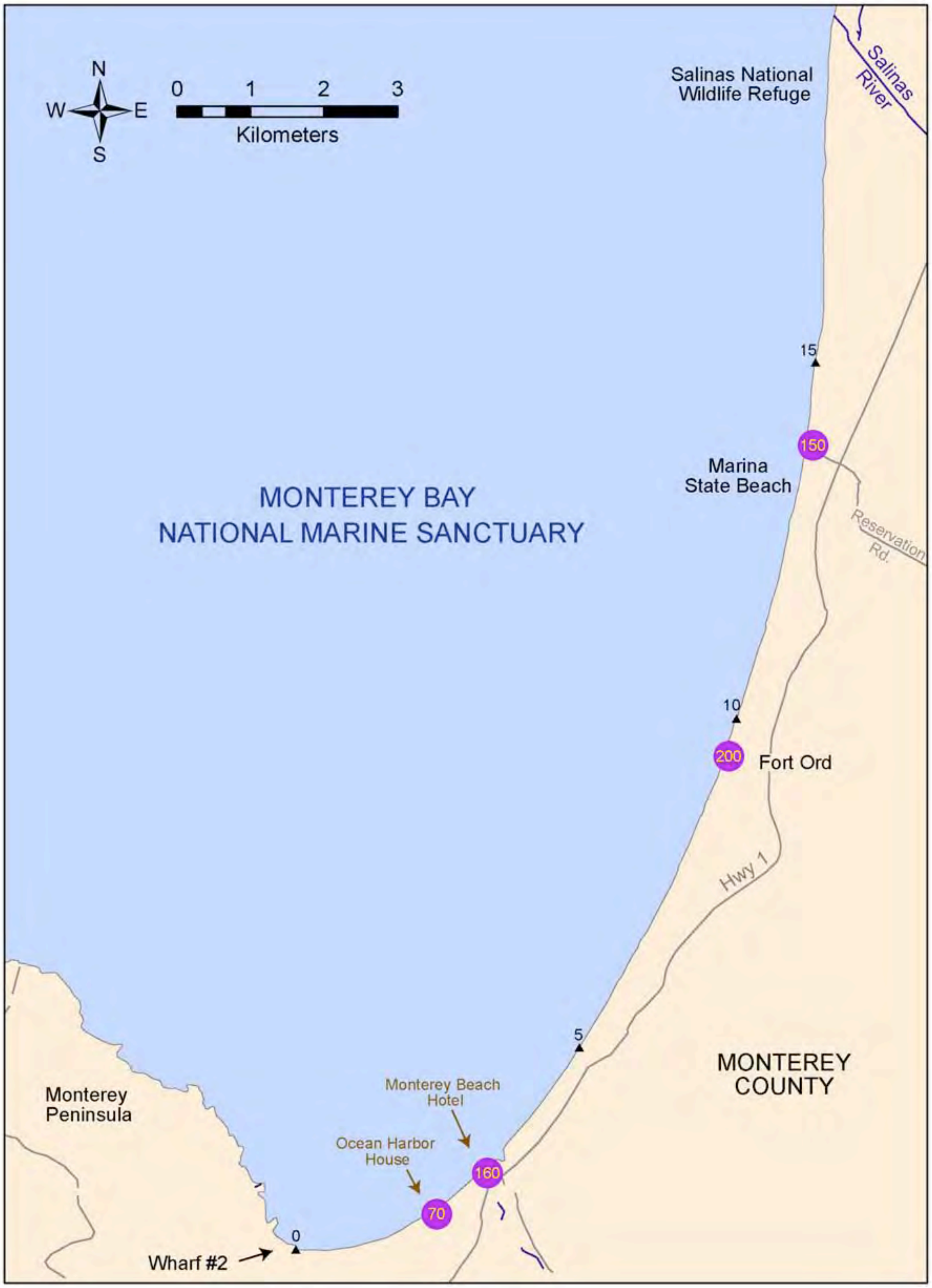

Figure 2.2: Coastal erosion rates reported in centimeters per year (purple circles), as determined by Gref (2004) of CSUMB. Rates were calculated over the years 1976-2004. Distances from Wharf #2 in Monterey are in kilometers (black triangles). For reference, 100 cm=3.28 ft.

d. Southern Monterey Bay Dune Erosion (Naval Postgraduate School)

Dr. Edward Thornton, of the Naval Postgraduate School (NPS) in Monterey, has compiled the one of the most comprehensive coastal erosion studies to date for the southern Monterey Bay (in press). The paper will most certainly become a valuable resource for planners in this erosion-prone region. Five graduate theses and NPS studies were combined to create a coherent, long-term assessment of coastal retreat and dune erosion from the Salinas River mouth to the Monterey north breakwater (Wharf #2); the region of interest selected by the sanctuary for this report was partially based on the area analyzed in the Thornton et al. study.

Statistically-valid average retreat rates were reported for six locations between Wharf #2 and the Salinas River mouth using a variety of methods. From 1940 to 1984, dune recession (defined as the retreat of the cliff-top edge of the dune, or the seaward extent of possible land use) was calculated using stereo-photogrammetry. A detailed LIDAR survey was utilized to quantify erosion that occurred over the 1997-1998 El Niño winter. Finally, a walking survey was completed in 2004 using a backpack-mounted kinematic GPS system for precision location of the dune cliff edge. The 1984 aerial photographs were re-analyzed to allow accurate comparison with the more recent LIDAR and GPS datasets.

Thornton et al. presented their data in several ways that may be useful for land use planning. Results are split up into two time periods, 1940 to 1984 and 1984 to 2004, based on the cession of swash-zone sand mining in the 1980's (see Section I-e). An estimated 128,000 m^3/yr of sand was removed from the littoral system between 1940 and 1984 because of mining, which is nearly 50% of the total annual volume of sand eroded from dunes over the same time period (270,000 m^3/yr). This interval also included two El Niño events (1956-57 and 1982-83) and linear coastal erosion rates ranged from 30 to 193 cm/yr (1.0 to 6.3 ft/yr). Erosion was most severe near Fort Ord, with slightly more subdued erosion to the north and south (Figure 2.3). Smith et al. (2005) also provide a comprehensive evaluation of this study in the context of shoreline management.

Figure 2.3: Coastal erosion rates in centimeters per year (blue circles) for the time period 1940-1984, as documented by Thornton et al. (in press). Distances from Wharf #2 in Monterey are in kilometers (black triangles). For reference, 100 cm=3.28 ft.

Despite intense erosion documented during the 1997-98 El Niño winter, when 1,820,000 m^3 of dune sand was lost, erosion rates for the 1984 to 2004 time period were lower than those reported from 1940 to 1984. From 1984 to 2004, coastal retreat was highest (143 cm/yr or 4.7 ft/yr) just south of Reservation Road, at Marina State Beach. Three erosion measurements in the middle of the study region, from a site approximately 1.5 km south of the former Stillwell Hall locale to Sand City Beach, ranged from 70 to 83 cm/yr (2.3 to 2.7 ft/yr). Two relatively low erosion rates were documented in the southern end of the study area: 26 cm/yr (0.85 ft/yr) near the Monterey Beach Hotel and 11 cm/yr (0.46 ft/yr) 0.9 km east of Wharf #2 (Figure 2.4).

Figure 2.4: Coastal erosion rates in centimeters per year (blue circles) for the time period 1984-2004, as documented by Thornton et al. (in press). Distances from Wharf #2 in Monterey are in kilometers (black triangles). For reference, 100 cm=3.28 ft.

According to Thornton et al., erosion rates appear to have decreased since sand mining was stopped. The rate of erosion has slowed more in the region south of Sand City. This may be because sand mining had been more intense in Sand City (81,000 m^3/yr) than in Marina (47,000 m^3/yr), therefore the relative slowing of erosion would be greater in the region downcoast of the former. Thornton et al. emphasize that, while removal of sand by mining may have impacted retreat rates to some degree, wave erosion is still the overriding erosion mechanism in SMB.

Planners will have to decide what their goal is when using the data presented by Thornton et al: if they want to compare this study with other studies that go back prior to 1984, it appears that an averaged (1940-2004) rate would be the most appropriate; if they want to get an idea of what current coastal retreat rates are, the 1984-2004 rates may be relevant. Yet Thornton et al. stress that caution should be taken when relying upon just the 1984-2004 rates because only 4 data sets were used in the calculation. Given the episodic nature of dune erosion in this region, a more conservative estimate of erosion would come from more robust, longer-term data (e.g., 1940-2004), despite the cession of sand mining (Figure 2.5).

Figure 2.5: Coastal erosion rates in centimeters per year (blue circles) for the time period 1940-2004, averaged from Thornton et al. (in press). Distances from Wharf #2 in Monterey are in kilometers (black triangles). For reference, 100 cm=3.28 ft.

e. USGS National Assessment of Shoreline Change

The United States Geological Survey (USGS) has a substantial project underway to calculate consistent, long-term erosion rates for all open coasts of the United States. Dr. Cheryl Hapke and Dave Reid, M.S., have been the lead west coast scientists working on this project entitled: *National Assessment of Shoreline Change: Historical Shoreline Changes and Associated Coastal Land Loss Along the Sandy Shorelines of the California Coast* (NASC) (Hapke and Reid in press). There are two main components of coastal retreat on the west coast: sandy shorelines and cliffs. The erosion rates for these distinct coastal landforms are calculated using different methods; together they provide a coherent picture of erosion. The sandy shoreline erosion rates will be completed first, followed closely by rates for cliffs. The NASC project is unique because it assesses erosion on a large scale, using consistent methods with quantifiable error. This will be especially useful for the sanctuary, which encompasses 276 miles of coastline.

The area of interest for this report, southern Monterey Bay, is entirely composed of sandy shoreline; thus, the NASC erosion rates may become available to MBNMS staff as early as spring 2005. Official public release of the NASC data will occur only after all relevant metadata and corresponding text has been compiled and reviewed as a USGS Open-File Report, most likely late in 2005. Due to liability issues, the NASC data may be used only for regional characterization and are not intended to be used for regulatory purposes. Sanctuary staff can work with the USGS to determine ways to use the rates for developing policies, while keeping within the bounds of the their liability disclaimer.

USGS retreat rates for the 18 km stretch of beach from the Monterey Harbor to the mouth of the Salinas River will be reported continuously at 50 m intervals. Four datasets were used to derive these rates, spanning over 120 years:

1) The earliest data were derived from National Ocean Service (NOS) T-sheets, historic survey maps created from the 1850s to the 1880s. The original maps have been scanned into a digital format and correlated with real-world latitudes and longitudes, a process known as georectification. Because of their age and the limitations of technology used to do the original mapping, accuracy of erosion rates derived from these maps is considered to be +/- 0.2 meters per year (m/yr); this error will be re-evaluated after the NASC processing is complete.
2) T-sheets from the 1930s were also used in the NASC study; these maps have similar limitations as described above (1).
3) Digital topographic maps, originally derived from aerial photography, were used to map the shoreline between the 1950s and the 1970s. These maps are also called Digital Raster Graphics (DRGs). DRGs generally have less error than T-sheets, meaning the difference between the digital map positions and real-world locations is smaller with DRGs.
4) The most recent dataset used in the NASC study was a 1998 LIDAR survey, which has excellent geospatial control and accuracy.

For each dataset, a shoreline was digitized in a GIS based on the available imagery (T-sheet or DRG); for the LIDAR imagery, the shoreline was determined by a computer program. Once all four shorelines were created in a digital format, a rate of change was calculated by linear regression at 50-meter intervals along the coast. This provides a high density of coastal retreat data, representing the longest possible time period, given availability of historical maps and imagery. In addition, retreat rates for different time periods can also be compared (e.g., 1880's to 1970's vs. 1970's to 1998). It is important to note that this sandy shoreline analysis assesses retreat of the entire coastline, not beach width change. In each set of imagery, a distinct shoreline is chosen that represents the same geomorphic position at each time interval analyzed. The selection of this shoreline feature is unrelated to how wide or narrow the beach is at that point in time.

f. Sand City Coastal Recession Evaluation (Haro, Kasunich and Associates, Inc.)

In 2003, Haro, Kasunich and Associates, Inc. (HKA) completed a comprehensive coastal recession evaluation for the city of Sand City, California (HKA 2003a). The purpose of the report was to review and update a 1989 shore erosion study for the area and to establish 50-year setback distances based on this revision. Retreat of the entire shoreline of Sand City, situated in between Seaside and Fort Ord, was established using 7 sets of maps and aerial photographs spanning from 1933 to 2003. While it appears that stereo-photogrammetry was not part of the methodology, HKA did use digital analysis that allowed them to match up features on each sets of photos for accuracy. There is no error analysis provided in the HKA report.

HKA determined that the average, long-term shoreline retreat rate for Sand City was 94 cm/yr (3.1 ft/yr), based on data from 1933 and 2003. The analysis was further narrowed to examine dune retreat rates, which, in theory, should be equal to the shoreline retreat rate on long time scales, for a section of coast from Bay Avenue to Tioga Road. According to these analyses, the bottom of the dune has retreated at an average rate of 73 cm/yr (2.4 ft/yr) in this region. HKA suggested that the discrepancies in these two rates are due to: an abnormally intense erosion event that affected the shoreline position in 2002; and differences in the shoreline mapping techniques between the 1933 (which was mapped as an average shoreline position) and 2003 (which shows the shoreline at a snapshot in time from a photograph). The erosion rate for the Sand City area is therefore assumed to be 73 cm/yr, a value which was used to establish 50 year setback locations in the HKA report. In addition, HKA recognized that cession of sand mining may cause a change in coastal erosion, presumably a decrease in the rate, but their cursory analysis of this effect was not sufficient enough to warrant a decrease in the erosion rate of 73 cm/yr.

g. Regional Synthesis of Available Erosion Data

Combining all available erosion rates described above serves to highlight the general erosion trends in this area (Figure 2.6). Rates are highest near Fort Ord and generally dissipate to the north and south. This is in agreement with the overall oceanographic patterns, which focus wave energy in the Fort Ord region, and with the extreme erosion witnessed around the former Stillwell Hall (see Figure 4.1). This trend is also consistent with preliminary results of the USGS *National Assessment of Shoreline Change* project (Reid 2005). It is important to note that, because of the diversity of time scales and methods by which erosion rates were measured in these various studies, Figure 2.6 should be used only to highlight general erosion patterns and as a guide to focus future erosion hotspot analyses.

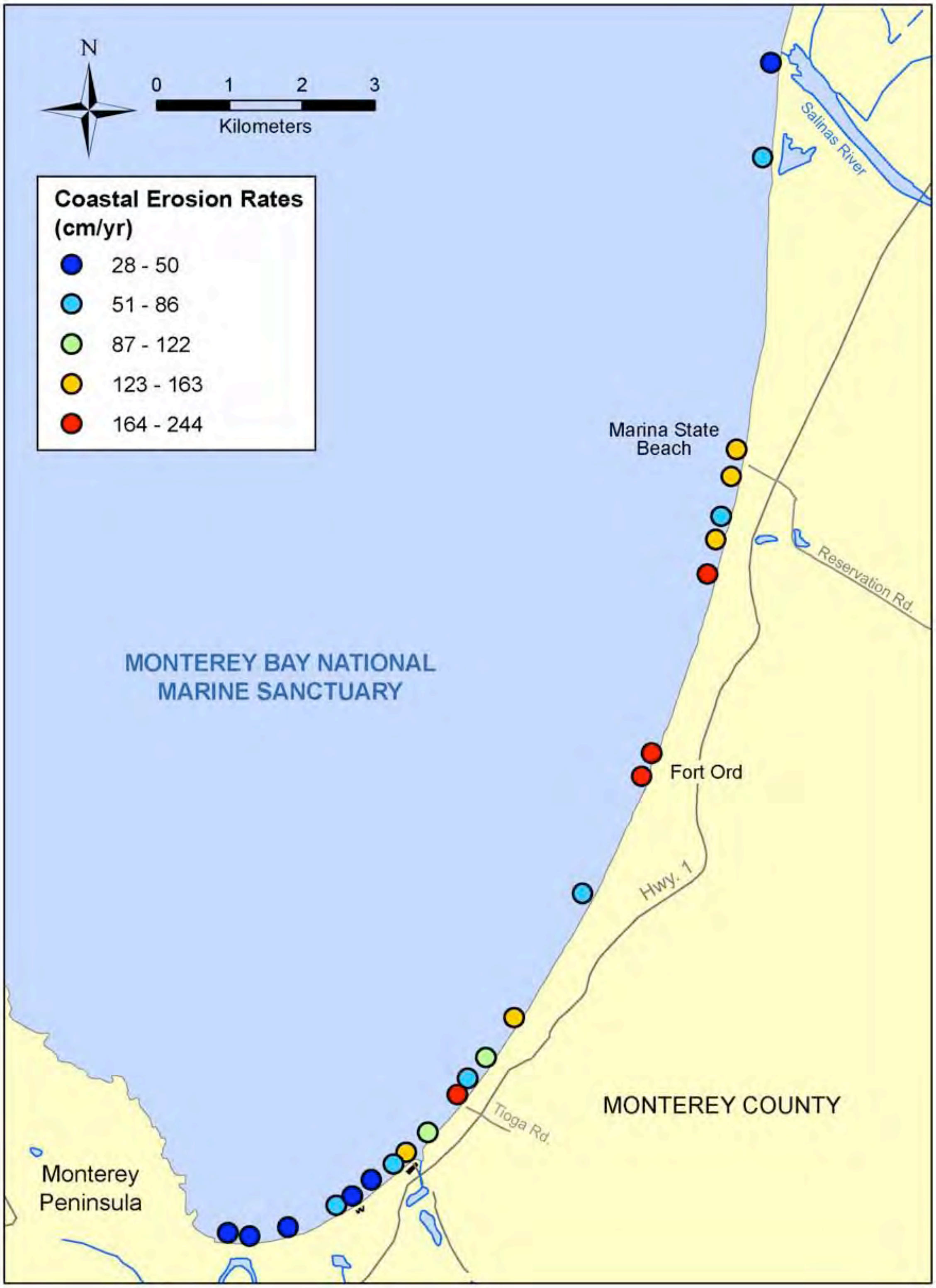

Figure 2.6: Coastal rosion rates for the study area, combining all available data (HKA 2003a; Gref 2005; Griggs et al. in press; Thornton et al. in press). Warm colors indicate more intense erosion than cool colors. For reference, 100 cm = 3.28 feet. See Appendix 2 for erosion rate data.

III. BEACH WIDTH CHANGE

All of the erosion studies described above assess overall retreat of the shoreline by measuring change in the location of a feature at the landward margin of the beach over time. Beach width change is a related, yet distinct, process. Seasonal changes in beach width due to changes in wave dynamics (Figure 1.7) are apparent to even the casual observer; beaches in southern Monterey Bay are generally narrow and steep in winter, yet wide and gently sloping in summer. Beach width can also change because of shifts in sand supply, either from natural or anthropogenic processes, such as sand mining, armoring, or damming coastal rivers. The relationship between beach width and coastal erosion is elucidated when beaches become narrower allowing waves to more readily attack the back-beach dunes, cliffs or bluffs, thereby increasing the rate of coastal retreat. Narrowing of beaches is also significant because of its impact on recreation and tourism. Thus, an understanding of the long-term beach width changes in southern Monterey Bay is important to this analysis of coastal erosion.

A recent USGS-UCSC study by David Reid, M.S., calculated beach width changes across the entire Monterey Bay, with aerial photography and NOS T-sheets spanning 70 years (2004) (see section II-e of this report for an explanation of NOS T-sheets). This long-term study provides an important understanding of trends in beach width, transcending seasonal fluctuations. Through his analysis, Reid showed that beaches in Monterey Bay are remaining approximately the same width over time; the system appears to be steady-state. Thus, while the overall shoreline has retreated over the past 70 years, beach widths have remained somewhat constant. Notable exceptions occurred when the back-beach landform (*e.g.*, a dune or cliff) had been fixed by coastal armoring. In these instances, shoreline retreat was prevented by the coastal armor and beaches narrowed in front of the structure, a process known as passive erosion (see Stamski (2005) for a description of this and other impacts of coastal armoring). According to Reid, the narrowing of beaches caused by fixing the cliff or dune with armor appears to extend beyond the edges of the structure, decreasing beach width on adjacent beaches as well.

Ironically, the erosion of coastal dunes, which occurs during times when beaches are narrow, is the dominant sand supply mechanism for beaches of southern Monterey Bay. A positive feedback relationship appears to exist between erosion and beach stability in this region. Over time (*e.g.*, 70 years), beach width has remained in steady-state, despite, and in fact because of, erosion of coastal dunes. The only time this system seems to be perturbed is when armoring prevents coastal retreat and beaches narrow permanently due to passive erosion. Thus, any attempts to prevent coastal erosion in this region will likely decrease beach width over the long-term, which may in turn increase the rate of dune erosion.

IV. ALTERNATIVES TO MANAGE COASTAL EROSION

Given the extreme erosion rates in southern Monterey Bay, progressive planning is essential for all parties involved in management of the coastal zone. The alternatives to cope with coastal erosion are numerous and new technologies are continually being developed. The most common approaches are discussed herein to provide sanctuary planners with information about how different management techniques may influence sanctuary resources; see Smith et al. (2005) for addition management options and suggestions.

a. Hazard Avoidance

The hazards associated with coastal retreat can theoretically be avoided if buildings and infrastructure are set back from the shoreline enough to ensure that erosion will not threaten the structures within their projected lifespan. For many coastal planners, including the California Resources Agency (2001), the California Coastal Commission (2005), and the City of Monterey Planning Department, this has been the primary, preferred alternative for zoning of new development. Unfortunately, establishment of adequate setbacks or rezoning are often not possible for existing structures, so other alternatives must be explored.

b. *Planned Retreat or Demolition*

When a structure is threatened by coastal retreat, property owners can demolish the building or relocate it landward, either on the same parcel or on an entirely different inland location. Neither of these choices is ideal for property owners, though they should be considered as serious, long-term solutions to this inevitable dilemma, given the rising costs other alternatives (Griggs 1986). For example, Stillwell Hall, built in the 1940’s as the Fort Ord soldier's club in Seaside, California, was torn down in March 2004 because the cost of both coastal armoring and relocating were too high (Figure 4.1).

Figure 4.1: The former Fort Ord soldier's club, Stillwell Hall, was demolished in 2004 because attempts to save the structure from collapsing into the ocean by emplacing riprap in front of the dunes proved to be too costly and ineffective. Left photo taken August 2003, prior to demolition. Right photo taken October 2004 after removal of structure and all riprap. Photographs copyright © 2002 Kenneth & Gabrielle Adelman (http://www.californiacoastline.org/). See Figure 5.1 for location.

c. Increasing Sand Supply to Beaches

i. Removal of Coastal Dams on Rivers

Dams on coastal rivers can severely limit sand supply along some stretches of the California coast (Willis and Griggs 2003). While this may not be an effective remediation technique for southern Monterey Bay, as described in section I-*e* of this report, this option should be considered for other littoral cells where coastal dams are preventing significant amounts of sand from reaching beaches. The State of California has recognized the need for a more holistic approach to sediment supply issues and is working to restore balance to littoral cells through the California Coastal Sediment Management Master Plan (CCSMW 2004).

ii. Beach Nourishment

Beach nourishment has been highlighted recently as a solution to coastal erosion; proponents of this alternative maintain that increasing beach width, by physically adding sand to a beach, buffers wave energy and slows retreat rates, while adding recreational benefits by augmenting beach width. Federal, state, and local government agencies are pursuing this method as a way to protect property from erosion damage, including the California Resources Agency (2001). The costs are generally very high and the net, long-term benefits of beach nourishment will vary greatly depending on local conditions (Leonard et al. 1990).

A survey of west coast beach nourishment projects determined that only 27% survived more than 5 years and 18% lasted less than 1 year (Leonard et al. 1990). In some cases, sand that was placed on a beach during summer was completely washed away the following winter. This is not unexpected given the high littoral drift rates that characterize most of the coast of California. A cost-benefit analysis of proposed nourishment projects should include site-specific evaluations of littoral budgets. In addition, the availability of an appropriate, cost-effective sand source and potential interference between beach users and sand transportation equipment should be addressed.

As mentioned earlier, there is evidence that lateral sand transport rates are low in the region and that the dominant transport mechanisms is offshore movement by rip currents (Smith et al. 2005; Thornton et al. in press). Thus, most of the sand eroded from beaches and dunes is being carried off onto the continental shelf, rather than being carried downcoast to nourish beaches. Artificially adding sand to beaches would likely be ineffective at building beaches in the littoral cell over more than one winter. Focused studies, such as those using tracers to track the patterns and volumes of sand transport downcoast, may constrain the likely success of a beach nourishment project in southern Monterey Bay.

iii. Groins

Beach nourishment projects may involve engineered coastal structures, such as groins, to retain sand on a target beach. A groin is essentially an artificial headland, built jutting out into the nearshore zone, perpendicular to the shoreline. Sand traveling downcoast gets trapped behind the groin, widening the beach upcoast of the groin. In many cases, a series of groins (referred to as a "groin field") are constructed to trap sand in pockets along a coast. By design, groins are situated both above and below the mean high tide line and would necessitate a permit from the sanctuary. The impacts of groins would be similar to those for coastal armoring, as described by Stamski (2005) and Griggs (in press), with even further influence on nearshore hydrodynamics and biology.

d. Offshore Breakwaters or Artificial Reefs

Most options for management of erosion involve alteration of the coastal zone, such as construction of seawalls against cliffs or depositing sand on the beach. Offshore breakwaters (or artificial reefs) are one way to avoid this coastal encroachment.

As a wave approaches the coast and the bottom shallows, the wave begins to feel friction with the seafloor. This slows the wave down, causing the wavelength (length from wave crest to wave crest) to decrease and the wave height to increase. Eventually, the wave will become too high to retain its shape and the wave will "break." In SMB, waves generally break right on or close to the beach, where depths are very shallow. The breaking waves are able to wash up the beach and, if conditions are right, coastal dunes and bluffs can be eroded. An offshore breakwater is engineered to create a shallow area away from the coast that will force waves to break. Wave energy is then drastically dissipated by the time it reaches the coast, thereby reducing dune erosion behind the breakwater.

The impacts of offshore breakwaters are not well documented, but the inferred influences are varied and may be severe. Primarily, offshore breakwaters involve an intense alteration of the seabed, necessitating a sanctuary permit. The breakwater would represent a change in habitat that could alter biological community dynamics in the region. During the construction phase, sessile organisms could be smothered and other plants and animals could be harmed by increased suspended sediment. By their nature, breakwaters change local oceanographic patterns, with implications for littoral drift, flow regimes, and wave dynamics. The migration patterns and behavior of organisms may be impacted by such changes to coastal hydrodynamics.

The location and angle of the breakwater must account for variations in regional wave direction and strength (Figure 1.7). Under some oceanographic scenarios, waves may bypass the breakwater, translating wave energy to the coast. Hence, the design and continued maintenance of offshore breakwaters requires significant engineering and impact assessment. As with many of these erosion management alternatives, the impacts and benefits need to be studied and weighed on a case-by-case basis.

e. Coastal armoring

By far the most popular option to manage shoreline retreat in California has been the construction of coastal protection structures (also referred to as coastal armoring). Approximately 10% of California's coastline is currently armored. The costs of armoring can be significant; millions of federal, state, and private dollars have been expended annually on shore protection, which can cost anywhere from $1800 to $7600 per linear foot of coast (Griggs in press).

Armoring varies widely in type of material, degree of engineering, and relative success in preventing coastal erosion and providing property protection (Griggs and Fulton-Bennett 1988). Riprap and seawalls are the most common armoring structures used in central California: riprap can be defined as any large (1 to 6 ton) rocks, or other hard material, used for coastal protection, with varying degrees of engineering; seawalls are continuous, rigid structures with vertical or concave faces. To clarify a common misconception, it is important to note that armoring is emplaced to protect buildings and infrastructure, not beaches (Kraus and McDougal 1996). Groin fields and beach nourishment are the common methods by which beaches are expanded, both of which are fundamentally different than armoring, which is constructed to halt erosion of cliffs, bluffs, or dunes that have buildings behind or on top of them, or to protect a building built on the backshore.

As of 1998, 24.3 km (15.1 miles) of the sanctuary's coastline have been armored (Griggs et al. in press). Various physical and biological impacts of coastal armoring may affect the resources of the sanctuary both directly and indirectly. Most coastal protection structures are placed above the high tide line, the official boundary of the sanctuary; yet some influences of armoring may impinge on the marine realm, and continued sea level rise and the accompanying coastal retreat will force many of these structures below the high tide line over time. The sanctuary recognized the significance of protection structures on the shoreline and has identified it as a critical issue in the Coastal Armoring Action Plan of the Joint Management Plan.

The impacts of coastal protection structures are of great concern to local governments, private property owners, and the public. The most commonly recognized affects of armoring are: visual effects, placement loss, access issues, loss of sand supply from eroding cliffs, passive erosion, and active erosion. In addition, there are potential impacts to the biological communities that utilize the coastal zone. These impacts are explained in detail in a recent National Marine Sanctuaries Conservation Series report (Stamski 2005).

f. Other Alternatives to Investigate

The following structural and non-structural responses to coastal erosion have been brought up at preliminary working group meetings and should be explored in greater detail as this process moves forward.

Site-specific structural responses:
- Seacave plugs
- Creation of a river delta
- Kelp forest restoration
- Jetty design modification (Moss Landing)
- Beach scraping (sacrificial berm)

Site-specific non-structural responses:
- Groundwater control
- Beach de-watering
- Vegetative
- Cobble berm

Other alternatives:

- Rubber dam
- Floating reef (wave energy dissipation)
- Inter-littoral cell transfer
- Dune nourishment
- Perched beach

V. CRITICAL EROSION SITES

Across the Monterey Bay region, coastal armoring has been the preferred solution to deal with coastal erosion. Yet, unlike the northern half of Monterey Bay, the southern coastline has relatively little development that has required emplacement of coastal armoring. There are a few notable exceptions that are referred to herein as “critical erosion sites” because erosion has been intense enough to threaten buildings or infrastructure within their lifespan. Figure 5.1 shows the distribution of coastal development from the mouth of the Salinas River to Wharf #2 in Monterey. The following is a brief description of the armoring in each of these locations.

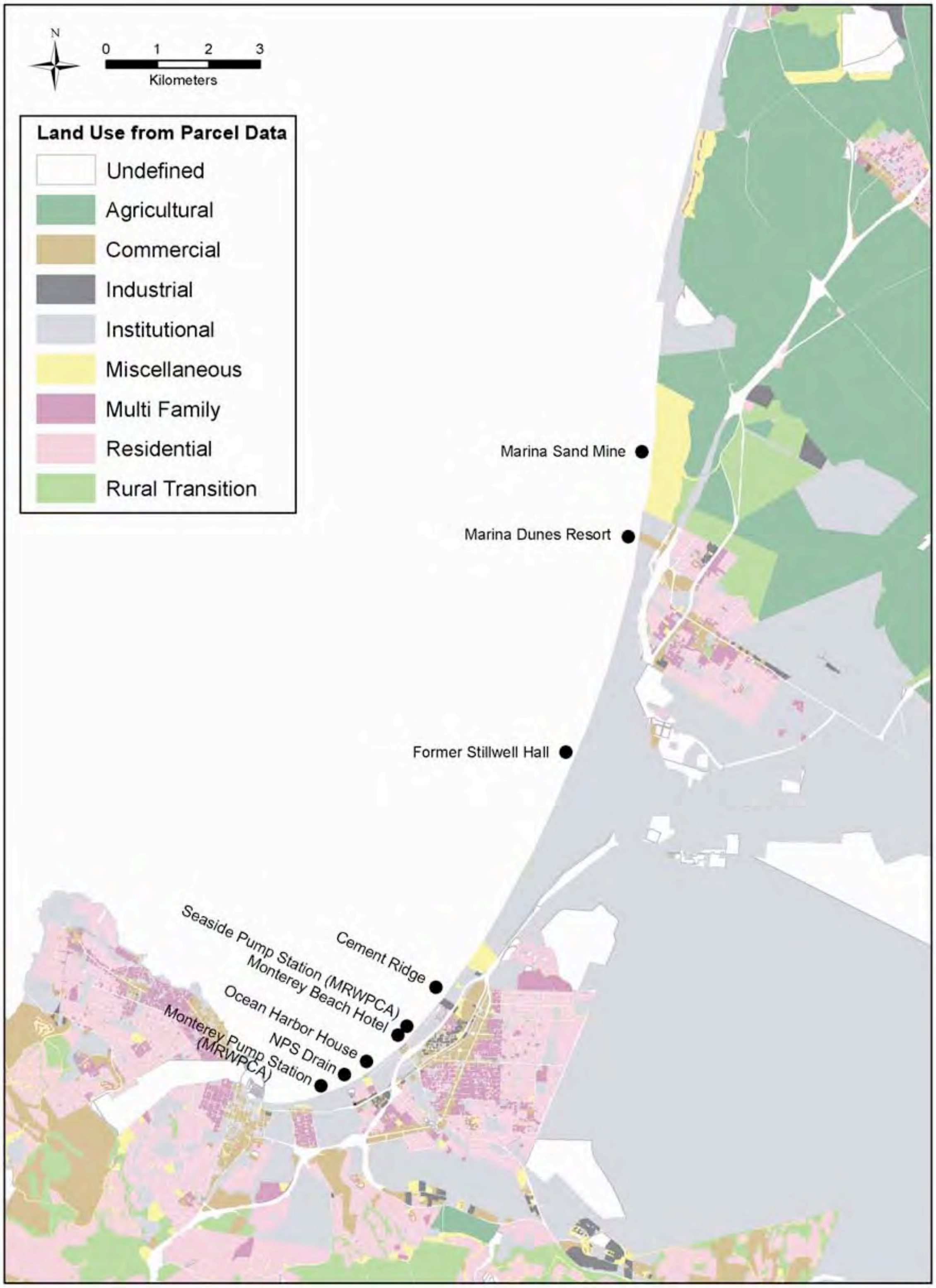

Figure 5.1: Approximate locations of development features along the SMB shoreline. Coastal armoring exists at the sites labeled: Cement Ridge, Monterey Beach Hotel, Ocean Harbor House and Naval Postgraduate School (NPS) Drain. Base layer shows generalized land use derived from parcel data.

a. Cement Ridge (Tioga Road, Sand City)

Remnants of a cement mixing facility are located at the end of Tioga Road in Sand City that forms make-shift coastal armoring (Figures 5.1 and 5.2). Concrete slurry was dumped here in a linear, shore-parallel pattern. The ridge formed by this cement is over 200 meters long and acts much the same way as a seawall (Thornton et al. in press). The impacts of this structure are similar to that of engineered coastal armoring in terms of blocking access, preventing natural shoreline retreat, and losing beach area both for recreation and as a habitat (HKA 2003a). The structure is an eye-sore to the community. In addition, riprap, composed mostly of un-engineered cement blocks, has been emplaced on the seaward side of Tioga Road as it turns parallel to shore.

Figure 5.2: Aerial photo mosaic of the concrete slurry "ridge" and other hard structures (indicated with yellow arrows) at the end of Tioga Road in Sand City, California. Photographs taken October 2004; copyright © 2002 Kenneth & Gabrielle Adelman (http://www.californiacoastline.org/).

b. Monterey Beach Hotel

In 1968, a 196-room, 4 story hotel was built directly on the beach in Monterey, which included a large, 100-m long seawall along three sides of the building (Griggs et al. in press; Thornton et al. in press) (Figures 5.1, 5.3, 5.4 and 5.5). The wall is composed of 6-foot wide keyed concrete panels that are jetted into place and anchored into shallow concrete mat slabs on which the hotel building itself is founded. Therefore, the stability of the hotel and the seawall are interdependent. Only the upper sections of the panels are grouted together, allowing water to get through the bottom half between the panels (HKA 2003b). Analyses by Haro, Kasunich and Associates, Inc. speculated that culvert drainage from Roberts Creek, on the north side of the hotel seawall, may be exacerbating coastal erosion in this region (HKA 2003b).

Given that this is known to be an eroding coast, it is not surprising that the Monterey Beach Hotel seawall came under attack in the early 1980's. In fact, the extreme waves of the 1982-83 El Niño event undermined the concrete and lead to a loss of fill behind the wall. More recently, storm waves coinciding with high tides during the winter of 2002 broke through the south wall and forced the hotel to place emergency riprap in the gap to prevent further damage (Figure 5.4). Large scour holes formed on the inside of the wall, as water penetrated between the panels. Excessive corrosion has occurred because of this damage. The hotel is becoming a prime example of the "peninsula effect:" while the adjacent coastline is retreating due to natural erosion, the seawall has fixed the coastline and is creating an artificial headland out of the hotel (Figure 5.5). As the hotel becomes further isolated, it will experience more and more damage from wave action. In addition, the fronting beach, which is a major attraction of the hotel, will be lost due to this passive erosion.

The seawall is in need of repair and the emergency riprap emplaced in 2002 must be removed if a new armoring permit is not issued. The hotel owners submitted an application to repair the seawall (3-03-022) to the California Coastal Commission (Commission). In 2003, the Commission requested an Alternatives Evaluation for the

Monterey Beach Hotel; Haro, Kasunich and Associates, Inc. (HKA), collaborated with others to determine and analyze these alternatives (HKA 2003b).

HKA addressed 8 alternatives to address the Commission request. The following alternatives were not recommended by HKA because they require unfeasible excavation that may compromise the structural stability of the hotel or because they do not meet the project objectives: 1) Do nothing; 2) Move hotel landward; 3) Reinforce and repair existing perimeter wall; 4) Riprap revetment seaward of existing perimeter wall; 5) New vertical sheet pile wall in same location as existing perimeter wall; 6) Reduce length of wall parallel to shoreline and relocate some parking; and 7) New vertical sheet pile wall landward of existing perimeter wall.

The alternative recommended by HKA was to build a new vertical sheet pile wall approximately 2 feet seaward of the existing perimeter wall. The wall would be longer than the current structure and would incorporate corrosion prevention measures. In addition, it was recommended that the wall be colored and textured to mimic surrounding natural conditions.

Figure 5.3: Aerial photograph of the seawall and riprap (at the far right end of the seawall) protecting the Best Western Monterey Beach Hotel in Seaside, California. Photograph taken October 2004; copyright © 2002 Kenneth & Gabrielle Adelman (http://www.californiacoastline.org/).

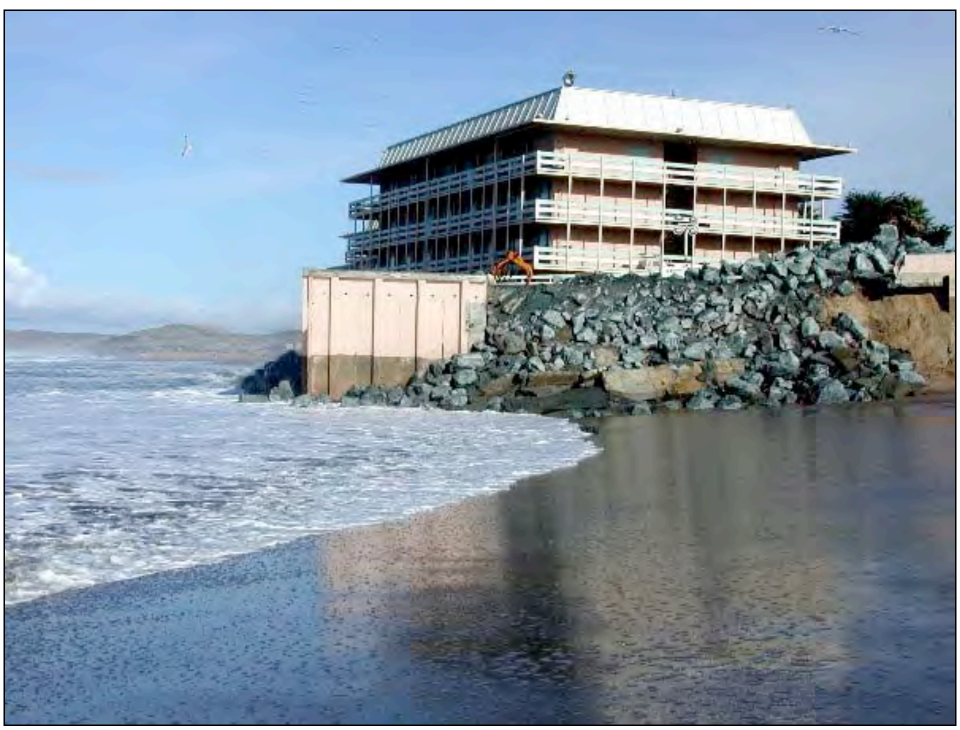

Figure 5.4: Wave run-up against the Monterey Beach Hotel seawall and riprap during the winter of 2002. Lateral access is cut off because of this coastal armoring. Photo: Doug Smith, CSUMB.

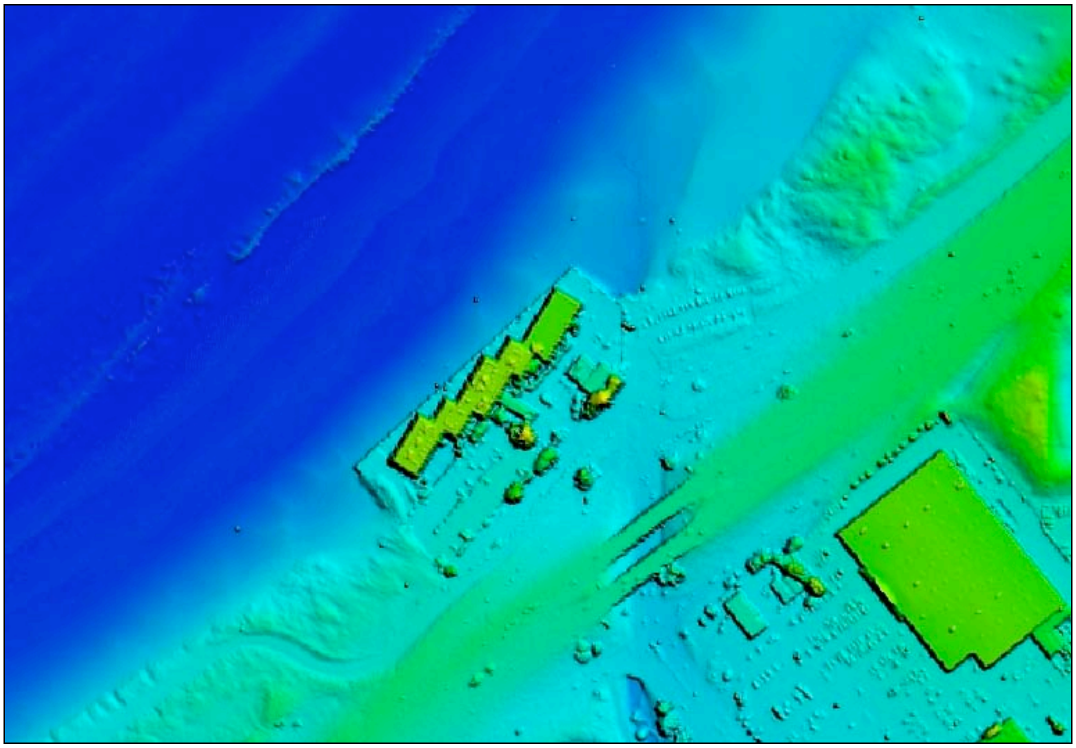

Figure 5.5: LIDAR elevation image of the Monterey Beach Hotel in 2003, showing the obvious erosion on either side of the hotel and the resultant "peninsula effect." Image: Doug Smith, CSUMB.

c. Ocean Harbor House Condominiums

Between 1972 and 1974, a 172-unit apartment complex, called Ocean Harbor House, was constructed directly on the coastal dunes in Monterey (Figures 5.1, 5.6, and 5.7). Severe erosion occurred in this region during the 1982-83 El Niño event, breaking water lines and posing a threat to sewer and electrical lines in front of Ocean Harbor House. By 1984, the piling supporting the front units were vulnerable to wave attack and 3,200 to 5,000 tons of emergency riprap was placed in front of the complex, despite the fact that the rocks had to be placed across over 100 m of public beach (PMC 2003; Griggs et al. in press).

Eventually, the city of Monterey forced the owners to remove the riprap and the front pilings were reinforced and driven deeper into the sand (50-55 feet). Around the same time, Ocean Harbor House was converted to condominiums, increasing the number of stake-holders from 1 to 172. Coastal retreat continued and, despite the reinforcements, additional riprap was needed to protect the front condominium units after the 1997-98 El Niño winter (Griggs et al. in press). The riprap is once again on city property and impacts the habitat and beach users in a variety of ways. In addition, the riprap emplaced in the late 1990's appears to be failing, as rocks settle into the sand and disperse (Figure 5.6 and 5.7).

The 172 owners of Ocean Harbor House have proposed removing the riprap and building a concrete seawall to protect their property from wave attack. This plan was approved by the California Coastal Commission, with substantial mitigation fees. The MBNMS has sent official letters of comment regarding the construction of a seawall in this region, requesting serious evaluation of other alternatives, such as planned retreat of the front units.

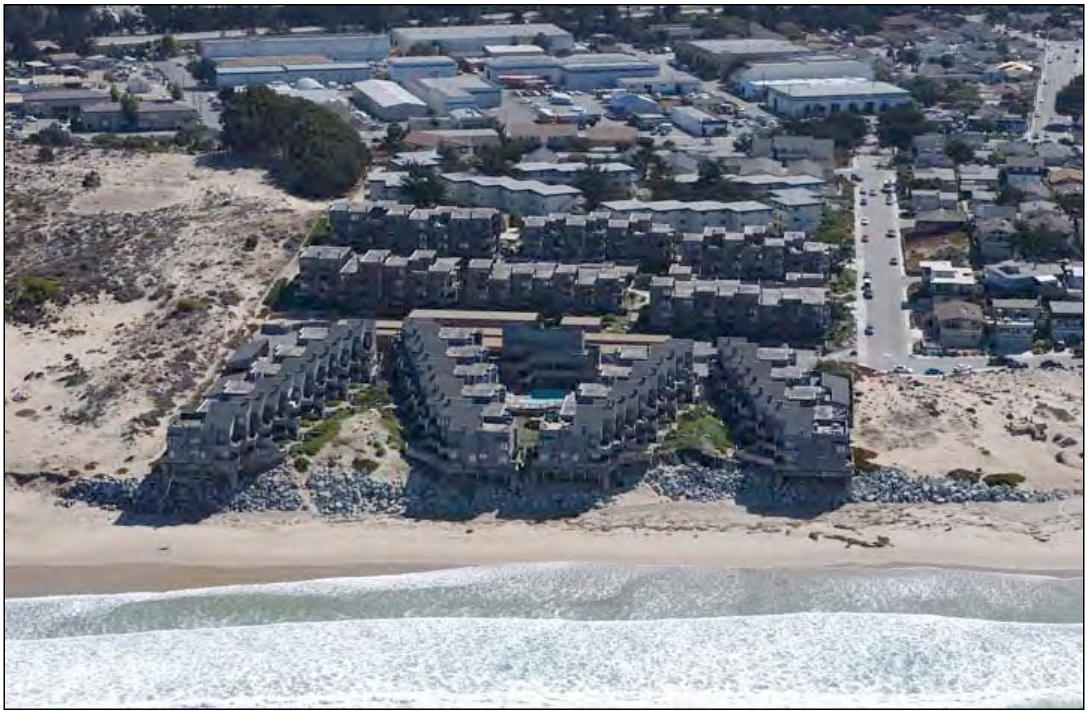

Figure 5.6: Aerial photograph of extensive riprap in front of the Ocean Harbor House Condominiums in Monterey, California. Photograph taken October 2004; copyright © 2002 Kenneth & Gabrielle Adelman (http://www.californiacoastline.org/).

Figure 5.7: Exposed pilings at the Ocean Harbor House condominiums in Monterey. Photo: Doug Smith, CSUMB.

d. NPS Storm Drain

A storm drain on the Naval Postgraduate School (NPS) grounds in Monterey has required emplacement of approximately 50 m of riprap to prevent wave damage (Figures 5.1 and 5.8). There is very little documentation on the history or future of this structure.

Figure 5.8: Aerial photograph of riprap on either side of a storm drain for the Naval Postgraduate School in Monterey, California. Photograph taken October 2004; copyright © 2002 Kenneth & Gabrielle Adelman (http://www.californiacoastline.org/).

e. Monterey Regional Water Pollution Control Agency (MRWPCA) Facilities

As discussed in section II-a, Philip Williams and Associates (PWA) completed an assessment of threat to MRWPCA facilities based on a 50-year planning horizon in southern Monterey Bay (PWA 2004). This risk evaluation incorporated threats from both short and long-term coastal erosion. Within the area of interest for this report, from

Wharf #2 in Monterey to the mouth of the Salinas River, several structures were designated as either "moderate" or "high" risk facilities.

According to the PWA report, the buried Monterey interceptor pipeline, from Tide Avenue to the Monterey Beach Hotel, has a moderate risk level and may be damaged in the next 50 years. The integrity of this pipeline may depend on the armoring now in place at Ocean Harbor House and the Monterey Beach Hotel. Other sections of the Monterey interceptor pipeline were designated as high risk: from the Monterey pump station to Tide Avenue and from the Monterey Beach Hotel to the Seaside pump station. The pipeline is threatened not only by lateral coastal retreat, but also by damage because of removal of overburden, and, in the case of the section from the Monterey Beach Hotel to the Seaside pump station, may be compromised within 25-30 years.

The Seaside pump station, situated only 75 feet from the shoreline, near the end of Canyon del Rey Road, was also determined to be high risk. PWA predicted that the facility may be threatened within 20 years and may be damaged by short-term events sooner. While PWA recommended further monitoring studies and reinforcement of the structure to prevent damage of the interceptor pipeline, they recommended relocation of the Seaside pump station because of imminent damage (see Figure 5.1 for locations of these facilities and associated structures).

VI. SUMMARY

The information compiled in this report demonstrates that the shoreline of southern Monterey Bay is actively eroding and that, while major development is somewhat limited in extent, structures that do exist near the coast are threatened by coastal retreat. On average, the shoreline is stepping back at a rate of 0.5 to 1.0 meter per year in this region. However, caution should be used when combining rates from disparate analyses. A more comprehensive, consistent study of coastal erosion, such as the upcoming USGS National Assessment of Shoreline Change, may be most useful for management within an agency with as much coastline as the Monterey Bay National Marine Sanctuary (MBNMS).

While the overall coastline is retreating over time in this area, the width of beaches along southern Monterey Bay appears to be fairly steady. The most noticeable deviation from this general trend occurs when hard armoring structures, such as riprap or seawalls, are placed at the base of dunes or on the beach, in which case the beach in front of the armor narrows over time. In addition, researchers indicate that the dominant transport mechanism for beach sand in this littoral cell may be rip currents that move sediment offshore, rather than along shore as is common in northern Monterey Bay. Thus, hard coastal armoring and beach nourishment may not be the most effective erosion management options for this region.

The lack of development along much of southern Monterey Bay provides the Monterey Bay National Marine Sanctuary and other agencies with an ideal, and increasingly rare, opportunity to be proactive in terms of land use development. Combining scientific knowledge of the region's dynamic coastline with sound management will undoubtedly help to conserve the natural beauty and value of this resource.

APPENDIX 1: Contact information for regional erosion experts (listed alphabetically).

Dr. Gary Griggs
Professor of Earth Sciences
University of California, Santa Cruz
Director, Institute of Marine Sciences

Interests:	Coastal processes and geologic hazards
Relevant Projects:	Living with the Changing California Coast; various journal articles on coastal armoring

Address:	Earth Sciences Department University of California, Santa Cruz 1156 High Street Santa Cruz, California 95064
Phone:	831-459-5006
Fax:	831-459-3074
E-mail:	ggriggs@es.ucsc.edu
Website:	http://es.ucsc.edu/personnel/Griggs/

Dr. Cheryl Hapke
Geologist
United States Geological Survey
Pacific Science Center

Interests:	Coastal hazards, cliff erosion, landslides
Relevant Projects:	National Assessment of Coastal Change Hazards, full report for sandy shorelines for entire sanctuary available September 2005, cliffed shoreline erosion rates available after that?

Address:	USGS Pacific Science Center 400 Natural Bridges Drive Santa Cruz, California 95060
Phone:	(831) 427-4744
Fax:	(831) 427-4748
E-mail:	chapke@usgs.gov

Alternative USGS Santa Cruz contacts for Dr. Hapke include David Reid and Dr. Bruce Richmond (below). Dr. Hapke is relocating to a USGS office in Rhode Island.

John E. Kasunich, P.E.
Haro, Kasunich and Assoicates, Inc.

Interests:	Coastal erosion, engineering, armoring
Relevant Projects:	Coastal Recession Evaluation for Sand City, Alternatives for Monterey Beach Hotel seawall

Address:	Haro, Kasunich and Associates, Inc. 116 East Lake Ave. Watsonville, CA 95076
Phone:	(831) 722-4175
Fax:	(831) 722-3202
E-mail:	n/a

David Reid, M.S.
Geologist / GIS Contractor
United States Geological Survey
Pacific Science Center

Interests: Coastal erosion, Monterey Bay geology, GIS applications
Relevant Projects: National Assessment of Coastal Change Hazards

Address: USGS Pacific Science Center
400 Natural Bridges Drive
Santa Cruz, California 95060
Phone: (831) 427-4759
Fax: (831) 427-4748
E-mail: dreid@usgs.gov

Dr. Bruce Richmond
USGS Geologist
United States Geological Survey
Pacific Science Center

Interests: Coastal erosion, coastal hazards
Relevant Projects: National Assessment of Coastal Change Hazards

Address: USGS Pacific Science Center
400 Natural Bridges Drive
Santa Cruz, California 95060
Address: Same as above
Phone: (831) 427-4731
Fax: (831) 427-4748
E-mail: brichmond@usgs.gov

Dr. Douglas Smith
Associate Professor Earth System Science and Policy
California State University, Monterey Bay

Interests: Watershed processes and restoration, geology, sedimentation
Relevant Projects: Karen Gref SMB erosion study (his student); modeling sea level rise in the bay; interest in impacts of coastal armoring

Address: Earth Systems Science & Policy, Bldg. 42
California State University Monterey Bay
100 Campus Center
Seaside, California 93955-8001
Phone: (831) 582-4696
Fax: (831) 582-4122
E-mail: douglas_smith@csumb.edu
Website: http://home.csumb.edu/s/smithdouglas/world/index.html

Dr. Edward Thornton
Professor and Associate Chairman, Oceanography Department
Naval Postgraduate School

Interests:	Wave mechanics, nearshore hydrodynamics, sediment transport
Relevant Projects:	SMB dune erosion study; SMB sediment budget (study in progress); theoretical studies of erosion due to rip currents in SMB

Address:	Nearshore Processes Lab Oceanography Department Naval Postgraduate School 327 Spanagel Hall Monterey, California 93943
Phone:	(831) 656-2847
Fax:	(831) 656-2712
E-mail:	thornton@nps.navy.mil
Website:	http://www.oc.nps.navy.mil/~thornton/

Dr. Gerald (Jerry) Weber
G.E. Weber Geologic Consulting

Interests:	Coastal processes, former UCSC professor, northern Monterey Bay sand transport, general central California geology
Relevant Projects:	Northern Monterey Bay sand transport study

Address:	G.E. Weber Geologic Consulting 129 Jewell Street Santa Cruz, CA 95060
Phone:	(831) 469-7211
Fax:	(831) 469-3467
E-mail:	jweber@pmc.ucsc.edu

APPENDIX 2: Table of erosion rates, locations, and authors. Coordinates are from the Teale Albers NAD83 projection in meters. These values were used in the creation of figure 2.6.

Author (Publication date)	Time span for rate calculation	Location Name	Rate (cm/yr)	X	Y
Haro, Kasunich and Associates (2004)	(1933-2003)	Sand City	73	-165189.921037	-153482.768572
Gref (2005)	(1976-2004)	Marina State Beach	150	-161395.208525	-144865.551280
Gref (2005)	(1976-2004)	former Stillwell Hall site	200	-162667.169362	-149055.141139
Gref (2005)	(1976-2004)	Monterey Beach Hotel	160	-166125.986791	-154628.093709
Gref (2005)	(1976-2004)	Ocean Harbor House	70	-166828.333047	-155164.227686
Thornton et al. (in press)	(1940-2004)	0.9 km from Wharf #2	36	-168290.160000	-155624.540000
Thornton et al. (in press)	(1940-2004)	2.9 km from Wharf #2	50	-166494.190000	-154853.830000
Thornton et al. (in press)	(1940-2004)	4 km from Wharf #2	101	-165784.860000	-154178.210000
Thornton et al. (in press)	(1940-2004)	6 km from Wharf #2	136	-164577.490000	-152588.500000
Thornton et al. (in press)	(1940-2004)	8 km from Wharf #2	82	-163550.720000	-150876.550000
Thornton et al. (in press)	(1940-2004)	13.5 km from Wharf #2	86	-161690.360000	-145746.730000
Griggs et al. (2005)	undefined	near Salinas River mouth	41	-161161.286272	-139427.382012
Griggs et al. (2005)	undefined	near Salinas River mouth	86	-161265.123928	-140706.493730
Griggs et al. (2005)	undefined	Marina State Beach	163	-161679.251446	-145006.040293
Griggs et al. (2005)	undefined	Marina State Beach	155	-161893.240981	-145823.815655
Griggs et al. (2005)	undefined	northern Fort Ord	208	-162031.805290	-146430.882593
Griggs et al. (2005)	undefined	Fort Ord	244	-162885.266904	-148949.972763
Griggs et al. (2005)	undefined	near Tioga Road	122	-165091.449844	-153071.126111
Griggs et al. (2005)	undefined	near Tioga Road	188	-165423.002492	-153515.895751
Griggs et al. (2005)	undefined	Monterey Beach Hotel	61	-166297.896064	-154485.590529
Griggs et al. (2005)	undefined	Ocean Harbor House	30	-168569.943205	-155469.248409
Griggs et al. (2005)	undefined	Monterey State Beach	28	-167767.274940	-155372.339216
Griggs et al. (2005)	undefined	near breakwater	30	-166866.298840	-154967.895446

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