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The Institute’s Hydrologic Engineering Center (HEC), located in Davis, CA specializes in the development, documentation, training, and application of hydrologic engineering and hydrologic models. IWR’s Navigation and Civil Works Decision Support Center (NDC) and its Waterborne Commerce Statistical Center (WCSC) in New Orleans, LA, is the Corps data collection organization for waterborne commerce, vessel characteristics, port facilities, dredging information, and information on navigation locks. IWR’s Risk Management Center is a center of expertise whose mission is to manage and assess risks for dams and levee systems across USACE, to support dam and levee safety activities throughout USACE, and to develop policies, methods, tools, and systems to enhance those activities.

Other enterprise centers at the Institute’s NCR office include the International Center for Integrated Water Resources Management (ICIWaRM), under the auspices of UNESCO, which is a distributed, intergovernmental center established in partnership with various Universities and non-Government organizations; and the Conflict Resolution and Public Participation Center of Expertise, which includes a focus on both the processes associated with conflict resolution and the integration of public participation techniques with decision support and technical modeling. The Institute plays a prominent role within a number of the USACE technical Communities of Practice (CoP), including the Economics CoP. The Corps Chief Economist is resident at the Institute, along with a critical mass of economists, sociologists, and geographers specializing in water and natural resources investment decision support analysis and multi-criteria tradeoff techniques.

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Top Left: Terraces North of Santa Cruz. (Source: Wikimedia Commons)

Bottom Left: Rock revetment at San Clemente Beach in Orange County, California.  
(Source: Rachel Grandpre)

Right Side: Map of California showing the 25 major littoral cells along the coast and the approximate direction of littoral transport.  
(Source: Developed from California Department of Navigation and Ocean Development 1977)
ABSTRACT

Much of the California shoreline is eroding. The width of the continental shelf since the ice age ended 18,000 to 21,000 years ago demonstrates the extent of erosion. Coastal sediment is in a constant state of flux because of natural forces from wind and waves; these forces continually wear away (erode) and sometimes build up (accrete) coastal land features. The natural erosion and accretion process provided California with healthy beaches, most of which were naturally narrow along coastal bluffs and cliffs, and with vibrant marshes and wetlands. Sand and sediment were being delivered to the shoreline from rivers and eroding cliffs and bluffs, which retreated unimpeded over time.

This situation changed dramatically once people built homes, commercial and industrial facilities, roads, railroads, and infrastructure along the shoreline. Beaches and tourism became a major economic force. To meet the needs of beach users, many beaches were artificially widened, and structures (e.g., groins) built to protect those beaches. Dams were built for flood control, and water supply and sediment collection basins built to reduce sediment runoff. Cliffs and bluffs were armored to protect against erosion. Jetties and breakwaters were built to protect harbors and promote navigation. Rivers were channelized, or even concreted, and navigation channels were created that serve as major sediment traps.

Studies conducted of beach-width and bluff-location show that approximately 40 percent of California beaches eroded in the early to late 1900s, increasing to 66 percent over the past 25 years. In general, relatively natural beaches have eroded less than beaches influenced by hard and soft engineering projects. This especially applies to beaches in Southern California. The common perception is that beaches are eroding. However, most beaches unaffected by such structures as groins or breakwaters appear to be fairly healthy when evaluated over long time frames (e.g., decades). The wide beaches that have been created by nourishment and stabilized by structures will, in time, retreat as reduced rates of nourishment take place. Since the 1930s, an average of 1.3 million cubic yards per year of sand was placed to widen narrow beaches in Southern California, but rates of nourishment have decreased over the past 20 to 30 years. These beaches face net sand losses over the coming decades, without continuing nourishment and stabilization efforts. While these beaches may be eroding back to their pre-nourishment widths, the reality for beachgoers is that wide beaches are eroding. In addition, even the 10 percent of the shoreline that has been armored is experiencing passive beach erosion.

Reduced sand supply in the littoral system plays a role in beach erosion. Hardened shorelines have reduced the availability of sand and sediments from eroding cliffs and bluffs that were a source of material for natural beaches. Construction of dams and reservoirs has reduced sediment delivered to the coastal waters by an overall amount of about 25 percent, and in Southern California that level approaches 50 percent.

The primary cause of erosion is wave energy, and the single most important factor producing erosion and shoreline change is the occurrence of large waves during high tides. These are influenced by such factors as individual storms, episodic El Niños, or the long-term Pacific Decadal Oscillation.

At risk from the erosion of beaches, cliffs, and bluffs, as well as marshes and wetlands, are billions of dollars in real estate and commercial properties, roads and railroads, the tourism industry, commercial
and recreational fishing, and habitat for fish and wildlife. In the context of rising sea levels, climate change with potentially increased storminess, and the knowledge that widened and protected beaches will continue to require periodic re-nourishment, short- and long-term strategies addressing the political, social, economic, and environmental implications of shoreline management are essential.

This report provides an assessment of coastal change in California; the social, economic, and environmental implications of erosion of the California shoreline; and the response to these issues at federal, state, and local levels.

The USACE National Shoreline Management Study Authority (PL 106-53) offers an opportunity to better understand the extent and causes of sediment movement (resulting in part from sea level rise and land subsidence), its impact on the economy and environment, as well as current sediment management practices and investments being made at all levels of government. The authority also includes several elements which suggest a broader context be considered. Specifically, this authority looks to understand the condition of US coastlines through the development of a report “…on the state of the shores of the United States…” which is to include “…economic and environmental effects caused by erosion…” and a “…description of resources committed by Federal, State, and local governments to restore and renourish shores.” Importantly it also authorizes the USACE to develop recommendations regarding “…appropriate levels of Federal and non-Federal participation in shore protection” and the “…use of a systems approach to sand management”. In short, this authority provides the USACE an opportunity to focus on sediment management within a broader coastal management context.

Authors’ Note: This report primarily uses the units of measurement that were reported in the references used to develop the report text (i.e., inches, feet, miles). However, metric units are used where references were reported in metric and conversion would not have been true to the reported information.
PREFACE

This report was prepared as a product of the National Shoreline Management Study (NSMS) authorized by Section 215(C) of the Water Resources Development Act of 1999 and managed by the U.S. Army Corps of Engineers’ (Corps) Institute for Water Resources (IWR). The USACE National Shoreline Management Study Authority (PL 106-53) offers an opportunity to better understand the extent and causes of sediment movement (resulting in part from sea level changes and land subsidence), its impact on the economy and environment, as well as current sediment management practices and investments being made at all levels of government. Specifically, this authority looks to assess and understand the condition of US coastlines through the development of a report “...on the state of the shores of the United States...” which is to include “...economic and environmental effects caused by erosion...” and a “...description of resources committed by Federal, State, and local governments to restore and renourish shores.” Importantly it also authorizes the USACE to develop recommendations regarding “...appropriate levels of Federal and non-Federal participation in shore protection” and the “...use of a systems approach to sand management”. In short, this authority provides the USACE an opportunity to focus on sediment management within a broader coastal management context.

Congress provided NSMS funding to document the physical, economic, environmental, and social impacts of shoreline change across various regions of the U.S. and will provide government policymakers, coastal engineers and scientists, and stakeholders with information about the coastal regions most in need of resilience planning.

The Regional Assessments, for various specific areas of the country, provide information to be used in the development of recommendations and alternatives for improved shoreline resilience and sediment management and to contribute to ongoing and future shoreline management policy discussions at the national and state levels. Recommendations can include pilot/demonstrations projects showing how a systems approach can provide a viable methodology.

This report is part of a series of other shoreline assessments around the country and serves as a companion to several other IWR NSMS reports that focused on the Corps of Engineers shore protection mission.
ACKNOWLEDGEMENTS

The preparers of this report recognize that numerous individuals in the Corps and outside the Corps have contributed to this report either directly through their contributions or indirectly through interactions observed in various meetings and report reviews. We thank them all for taking the time to inform our team about facts and perceptions that were relevant to the report purpose especially the various members of the California Coastal Sediment Management Workgroup. A number of people need to be thanked for their reviews of some portion of the report. These include:

1. U.S. Army Corps of Engineers –
   Institute of Water Resources – Ms. Marriah Abellera, Mr. George W. Domurat
   San Francisco District – Mr. Tom Kendal, Mr. John Dingler, Mr. James Zoulas
   Los Angeles District – Ms. Heather Schlosser, Ms. Susie Ming
   South Pacific Division – Ms. Anne Sturm

2. State of California –
   California Natural Resources Agency – Mr. Brian Baird (ret.), Mr. Chris Potter
   California Geological Survey – Mr. Clif Davenport
   California Coastal Commission - Ms. Lesley Ewing, Mr. Mark Johnsson
   California Boating and Waterways – Mr. Kim Sterrett (ret.)
   University of California, Santa Cruz - Professor Gary Griggs

3. U.S. Environmental Protection Agency –
   EPA, San Francisco – Mr. Brian Ross
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EXECUTIVE SUMMARY

California’s coastline is eroding. The loss (erosion) and accumulation (accretion) of sand used to fluctuate naturally as sediment flowed down rivers, broke away from bluffs, and was shaped by waves and wind. This is no longer the case. Development and other factors, such as severe storms, sea level rise over the last century have disrupted these natural processes and degraded habitat, that was home to shorebirds and other wildlife. Beaches and shoreline-based tourism became a major economic force. To meet the needs of beach users, various shoreline management methods have been employed to counteract the impacts of the man-made sediment disruption. Many beaches were artificially widened, and structures (e.g., groins) were built to protect those beaches and eroding coastline. Cliffs and bluffs were armored to protect against erosion. Jetties and breakwaters were built to protect harbors and promote navigation. Rivers were channelized, or even paved, and navigation channels were created that serve as major sediment traps.

About 40 percent of California beaches had eroded by the early to late 1900s, increasing to 66 percent over the past 25 years. While high erosion rates occur at various points statewide, some of the highest erosion rates have occurred in southern California. Because of the variety of shoreline landscape, significantly different erosion rates are found along the shoreline, where some beaches have eroded up to 10 feet per year. The rates of erosion along California’s unique and picturesque coastal cliffs range from a few inches to a foot per year. The harder granite cliffs and bluffs are generally resistant to erosion, whereas bluffs composed of looser sediments tend to experience higher erosion rates.

While cliffs can be major contributors to beach sand, sediment from rivers constitutes about 87 percent of the sand entering most of California’s nearshore environment and beaches, and contributes 90 percent of the sand to southern California. Unfortunately, damming of rivers has reduced that amount by 25 percent, a loss of approximately 2,500,000 cubic yards per year, mostly in central and southern coastal California.

The loss of sediment supplying beaches is not good news for a state that draws so much wealth from the coast. Reductions in beach width and associated loss of revenue was quantified in a study on San Clemente that predicted a 50-percent increase in beach width could generate $3.1 million in consumer surplus per year. At one beach in San Diego, it was estimated that maintaining current beach width could result in over $300 million in increased revenue for local vendors.
Our shoreline serves as critical coastal infrastructure for the state’s economy, providing an economic engine and protecting billions of dollars of both public and private investment. With so much at stake, significant efforts are underway to adopt policies and plans to improve shoreline resilience and strengthen this economic backbone. The California Coastal Sediment Management Work Group has been working since 2006 with regional and local agencies to develop a series of Coastal Regional Sediment Management Plans, specific to individual regions, identifying strategies to address sediment imbalance issues affecting infrastructure, sea level rise and habitat within each region. The state is taking other actions to address coastal resiliency that complement this sediment management effort. For example, the California Natural Resources Agency is currently updating “Safeguarding California Plan” http://resources.ca.gov/docs/climate/Final_Safeguarding_CA_Plan_July_31_2014.pdf. This National Shoreline Management Study is an integral component of the state’s coastal planning; it can help inform priority investments to strengthen coastal resilience and ensure long-term economic benefits.
1. INTRODUCTION

The California Regional Assessment, which is part of the National Shoreline Management Study (NSMS), contributes to ongoing efforts to provide an accurate description of the status of the United States shoreline and provides information for future shoreline management policy discussions and management actions. The U.S. Army Corps of Engineers (USACE) was authorized to undertake the NSMS under Section 215(c) of the Water Resources Development Act of 1999 (WRDA, P.L. 106-59), which defined key areas to be included, specifically:

- A description of (1) the extent of, and economic and environmental effects caused by, erosion and accretion along the shores of the United States; and (2) the causes of such erosion and accretion;
- A description of resources committed by federal, state, and local governments to restore and nourish shores;
- A description of the systematic movement of sand along the shores of the United States; and
- Recommendations regarding (1) appropriate levels of federal and non-federal participation in shore protection; and (2) use of a systems approach to sand management.

This assessment describes economic and environmental effects that result from natural and anthropogenic influences on sediment processes along the California shoreline, including erosion and accretion. California is aggressively undertaking the development of a coastal sediment master plan to help guide political, regulatory, environmental, educational, and process-related efforts involving or affecting coastal sediments. The California Coastal Sediment Management Workgroup is providing leadership in shaping and facilitating a comprehensive systems approach to sediment management along the California coast. Information about the process, players, products and experiences, and lessons learned of the workgroup has informed this regional assessment.

The 1971 National Shoreline Study

In the late 1960s, the public and Congress expressed concerns about shoreline erosion problems and the need to protect the nation’s shorelines (Stauble 2004). In Section 106a of the 1968 River and Harbors Act (RHA, P.L. 90-483), the 90th Congress authorized USACE to conduct a national assessment of coastal erosion and an evaluation of the existing federal shoreline protection program. In response, USACE published the National Shoreline Study. The main goals of the National Shoreline Study were to identify shorelines threatened by erosion and to develop recommendations regarding sediment management, shoreline restoration, and minimizing damages in coastal areas affected by erosion.

The National Shoreline Study was the first nationwide look at coastal erosion and the federal shore protection program. The study produced 12 documents, including individual reports on the topics of shore management guidelines (USACE 1971a), shore protection guidelines (USACE 1971b), shoreline erosion (USACE 1971c), and a series of 9 regional inventories. The National Shoreline Study concluded that 20,500 miles of the nation’s shoreline were undergoing “significant erosion” (USACE 1971c). The qualitative criteria for identifying “significant erosion” were based on rate of erosion, economic factors, industrial use, recreational use, agricultural use, navigational needs, demographic distributions, and ecological impacts.
The National Shoreline Study assessment sub-divided areas experiencing “significant erosion” into 2,700 miles of “critical erosion” and 17,800 miles of “non-critical erosion” (USACE 1971c). Within California, estimates indicated that 1,550 miles were “significantly eroding” with 80 miles considered “critical” and 1,470 miles designated as “non-critical” (USACE 1971c; USACE South Pacific Division 1971). Areas of “critical erosion” were determined based on predictions for population and land use into the year 2020, environmental effects of past erosion, ownership, and land use regulations. Non-quantitative methods and criteria were used to develop the conclusions of the 1971 National Shoreline Study; therefore, the results do not allow for quantifiable comparisons to present-day erosion rates (Stauble 2004).

Major needs identified in the National Shoreline Study (USACE 1971c) included:

1. Coordinated action by federal, state, and local governments in concert with action by corporate and private owners to arrest erosion of some parts of the national shorelines;
2. Coordinated and comprehensive planning and management to ensure the use of the national shoreline in the national best interest;
3. Intensified research and investigation of the processes contributing to shoreline erosion and development of improved methods and techniques for controlling erosion; and
4. Identification and development of improved technologies and methods for controlling erosion.

In the 46 years following the National Shoreline Study, the nation’s coasts have undergone a substantial transformation with respect to the regional geomorphology, ecology, development, land use, population, and management practices. With these changes comes a need for an overview of the present and future status of the shoreline. Also, since the 1971 National Shoreline Study was published, there have been major advancements in our understanding of coastal processes, how coastal climate varies on various timescales (e.g., La Niña and El Niño cycles), and how sediment moves along the shoreline. There has been extensive research and publications by various federal and state agencies, private consultants, and academia that provide detailed information on the changing shoreline. Improved technologies such as Light Detection and Ranging (LiDAR) and Global Positioning System/Geographic Information System (GPS/GIS) allow for a much more accurate measurement and analysis of shoreline erosion and accretion (Box 1). There is improved knowledge of accelerated climate change and the ways in which its effects, such as changes in sea level, will increase the vulnerability of our shorelines.

**Box 1. Light Detection and Ranging (LiDAR)**

LiDAR is an active remote sensing system that can be operated in either a profiling or scanning mode using pulses of light to illuminate the terrain. LiDAR data collection involves mounting an airborne laser scanning system onboard an aircraft along with a kinematic GPS receiver to locate an x, y, z position and an inertial navigation system to monitor the pitch, roll, and heading of the aircraft. By accurately measuring the round-trip travel time of the laser pulse from the aircraft to the ground, a highly accurate spot elevation can be calculated.
The 2017 National Shoreline Study

Previously published NSMS (under WRDA 1999) assessment reports include the North Atlantic Regional Pilot (Leuck, Willis and Trott 2011, draft), and a first phase National Assessment (December 2010, draft) that examined the analytical factors relative to the four eastern regions of the U.S. shoreline: North Atlantic, South Atlantic, the Gulf of Mexico, and the Great Lakes. In addition to the North Atlantic and California reports, detailed regional assessments are underway or planned for all the remaining U.S. coastal regions, including: South Atlantic, the Great Lakes, the Gulf of Mexico, Oregon and Washington, Hawaii, and Alaska. The NSMS series has produced a wealth of information on economic and environmental effects of erosion and accretion along U.S. shorelines, and systematic approaches to managing sediments and associated impacts. These can be found on the NSMS website: www.nationalshorelinemanagement.us.

Purpose and Objectives of the California Regional Assessment

The purpose of this California Regional Assessment is to describe the physical, environmental, and economic aspects of erosion and accretion of the coastal shoreline for the entire state, and to describe the systems approach to sediment and shoreline management advocated by a collaboration of federal, state, and local agencies and key stakeholders in California. The study objectives are to:

- Describe regional characteristics including shoreline habitat, coastal and sediment processes, and specific features for the major regions of California, including differences in effects and magnitude of erosion and accretion along the northern coast, the central coast, and the southern coast;
- Identify the economic and environmental impacts of erosion and accretion;
- Identify the potential effects of future sea level rise and climate change to the shoreline and their effects on sustainability and resilience; and
- Describe the current approach in California (including key tools and products of the California Coastal Sediment Management Workgroup) in applying a systematic methodology to sediment and shoreline management.

This California Regional Assessment provides information to be used in the development of recommendations for improved shoreline and sediment management, and in particular, appropriate levels of federal and non-federal participation in shore protection, and use of a systems approach to sediment management. The information in this report is intended to contribute to ongoing and future shoreline management policy discussions at the national and state levels.

General descriptions of the California coast are included in the report at a regional and statewide level; existing information was used for these descriptions, and this document does not provide specific details for every reach of the California coastal littoral zone. Several case study examples are included for illustrative purposes. More specific information and more detailed analyses are provided in the references identified in the text.
Overview and Summary of the California Regional Assessment

Description of the California Shoreline

The California coast can be divided into two physically dissimilar regions: southern and northern. The boundary occurs at Point Conception, where both the coastal alignment and the physical environment change abruptly. The northern California shoreline is fully exposed to winter storm waves generated in the North Pacific, while Southern California is afforded partial shelter from these waves by Point Conception and numerous offshore islands.

For this California Regional Assessment, the shoreline north of Point Conception is divided into the central\(^1\) and northern regions.

- The northern coast of California is rugged with an irregular shoreline of steep cliffs, bluffs, small offshore islands, and sea stacks. In some areas, there is just a sliver of sand between the coastal mountains and the ocean. The shoreline is characterized by prominent headlands that are interspersed with stretches of sea cliffs and small pocket beaches. Some areas contain rocky bluffs and outcrops with relatively few beaches. The area experiences severe storms, high rainfall, and high-energy waves. Throughout the area, the population density is low.

- The central coast of California is a diverse region that transitions from the wet climate and high wave energy of the northern coast to the dry climate and lower-energy waves of the southern coast. With marine terraces, coastal bluffs, high coastal slopes, large dune areas, coastal mountains and their basins, the central shoreline presents a unique and beautiful stretch that includes San Francisco Bay, which is the largest bay on the West Coast.

- In the most highly developed coastal region, Southern California has more urban coastal areas and lower-energy waves compared to the north and central regions. The shoreline typically is backed by coastal plains and marine terraces. Expansive sandy beaches dominate, as in the case of Santa Monica Bay, although they may be separated by rocky headlands such as Palos Verdes Peninsula.

Shoreline Management Practices: Contributors to Erosion and Accretion

Shoreline management generally consists of hard structures, soft structures, and plans, policies, and regulatory measures.

- Hard structures, such as seawalls, bulkheads, revetments (e.g., designed and well-placed riprap), groins, and breakwaters are permanent works that armor the shoreline to prevent further erosion landward of the structure. Over 10 percent of California’s shoreline is armored. In the four most urbanized counties (i.e., Ventura, Los Angeles, Orange, and San Diego), 33 percent of the 224 miles of shoreline is armored.

- Soft structures utilize natural resources and systems to maintain the shoreline. Some coastal management projects combine both hard and soft stabilization techniques to address problems in the coastal zone. For example, beach nourishment is used for erosion control, reducing coastal flood

\(^1\) The economic analysis in Section 4 broke the central region from the southern region at Point Buchon, about 60 miles north of Point Conception.
damage, reducing wave impact damage, increasing recreation, and enhancing habitats for threatened and endangered species. In the best situation, beach nourishment projects are integrated with navigation projects, so that a source of sediment (e.g., navigation dredging) is matched with a need for material (e.g., a beach).

- Plans, policies, and regulatory measures are in place addressing erosion and accretion actions. Many were developed more than 50 years ago, while others are more recent. Griggs, Pepper, and Jordan (1999) conducted a comprehensive review of coastal policy and planning, as has the California Coastal Sediments Workgroup; further evaluation is needed, especially considering the potential disruptions caused by sea level rise.

### Sand Budgets: Necessary Baseline Information for Managers

The California shoreline has been divided into 25 self-contained littoral cells or beach compartments (figure on front cover). Detailed sand budgets for all of California’s major littoral cells were developed in the mid-2000s.

A littoral cell is a distinct geographical area along the shoreline that consists of sand sources (such as rivers, streams, and eroding coastal bluffs) that provide sand to the shoreline; sand sinks (such as coastal dunes and submarine canyons) where sand is lost from the shoreline; and longshore transport or littoral drift that moves sand along the shoreline.

Understanding the sand budget for a geographical area (e.g., the littoral cell) is the first step for managers in assessing the impacts of erosion and accretion, and developing potential responses.

### Erosion and Accretion along the Shoreline

A significant portion of the California coast has been actively eroding since the last ice age. Recently, human activities along the California shoreline have substantially altered natural erosional processes by drastically reducing the natural supply of sediment to the shoreline and changing the movement of sediment along the coast. Harbor jetties, groins, and breakwaters interrupt the natural transport of sand along the shoreline. Dams and debris basins, channelized rivers and streams, hardened shorelines, land areas covered with impervious surfaces, and in-stream sand mining have all combined to substantially decrease the supply of beach-compatible sediment reaching the shoreline.

- In the past, California’s coastal rivers naturally supplied sediment such as gravel, sand, silt, clay, and mud to the coast. According to a study funded by the California Department of Boating and Waterways, coastal dams now capture more than one-fourth of the average volume of sand that would otherwise make it to the coast, a volume of over 2,500,000 cubic yards per year.

- The net erosion rate for the last 50-60 years was an average of -0.2±0.4 meters (-0.7±1.3 feet) per year. The highest rates of accretion were in northern California and the highest rates of erosion were in Southern California.

- In general, coastal cliffs and bluffs are eroding about one foot per year. At some sites, erosion is negligible while at others the unconsolidated cliff materials are eroding at 5 to 10 feet per year.
The armoring of sea cliffs, which prevents cliff and bluff erosion, has reduced the sand supply to state beaches by an average of 11 percent, and some local areas in Southern California experience reductions of 50 to 80 percent.

In southern Monterey Bay, mining of beach sand has taken place for decades at a rate of about 180,000 cubic yards per year.

Beach nourishment from dredging of offshore sources has added an average of 1,300,000 cubic yards per year to the overall sand budget for California’s major littoral cells. All of the nourishment has taken place along the Southern California shoreline, but the number of nourishment projects has declined greatly in recent years. Beach nourishment began in 1935, and the majority of projects took place during the 1950s to 1970s as a result of large coastal construction projects providing a large amount of sand. Reduced beach nourishment in recent decades represents an overall sediment supply reduction that is greater than that lost as a result of dams and armoring. The decline in beach nourishment projects after the 1970s also coincided with the shift in climate regimes from a dry, calm La Niña to a wet, stormy El Niño. That shift increased the fluvial supply of sediment by 20 times. This shift in climate to El Niño resulted in an increase in natural sand supplied to the beaches and helped to make up for the concurrent reduction in beach nourishment.

Long-term analysis, which accounts for the influence of El Niños and the Pacific Decadal Oscillation, shows that many natural beaches experienced fewer effects of erosion than some beaches located near hard engineering structures, and beaches that have been nourished experienced more extensive erosion as they retreated to their natural state. Engineered structures, such as dams and armoring, appear to have an impact on erosion of a number of Southern California beaches. Since the hard engineering structures were likely put in place because of erosion, a direct correlation cannot be made without specific studies on their direct effects.

Dredging is the primary response to sediment accretion in California’s harbors and ports. Between 1996 and 2005, The USACE dredged, on average, 4.3 million cubic yards of sand per year from 25 navigation projects along the California shoreline, two-thirds of which occurred in the southern part of the state. Coupling dredging operations (for bypass or navigational projects) with beach nourishment (beneficial use) is generally viewed as an excellent strategy to simultaneously address accretion and erosion; the issue is frequently the costs of sand transport and matching the dredging project with beaches that need the sand.

Over the last decade, the importance of sediments in the littoral zone has been increasingly recognized by USACE and other federal and state agencies. Since the early 2000s, the concept of systems approaches to sediment management have influenced acceptable disposal alternatives for dredged material. These now include placement into the littoral zone. Appropriate conditions have to be met including grain size, chemical and toxicological quality of the dredged material, depth of closure, and an acceptable receiving environment, such as longshore currents.
The California Coastal Erosion Survey

The California Coastal Sediment Management Workgroup sponsored an assessment of the California shoreline to identify areas where historical or current erosion is of concern to federal, state, or local entities. The survey, which was completed in 2010, resulted in a list of 56 separate beaches where erosion is having impacts and threatening such resources as: public infrastructure (e.g., roads and sewage pipelines), beach recreation opportunities, current and future residential and commercial property, bird and turtle habitats, and tourism. After the initial identification of beaches, conceptual solutions to the erosion problems were identified and planning is now ongoing to address those issues.

Impacts of Sea Level Rise on Erosion and Accretion

The California shoreline is eroding, and sea level rise will accelerate that process with enormous implications for local and statewide economies, infrastructure, existing residential and commercial development, commercial and recreational fishing, beaches and dunes, flood control, marshes, mudflats, wetlands, and estuarine health. For an assessment of sea level rise, it is helpful to divide the shoreline at Cape Mendocino. To the north, the Cascadia Subduction Zone causes an uplifted shoreline. To the south, the margin is dominated by the transform or lateral motion of the San Andreas Fault. According to the National Research Council in their 2012 report assessing sea level change in California, Oregon, and Washington:

- In the past 6 to 10 decades, tide gauges show that relative sea level increased south of Cape Mendocino and decreased north of Cape Mendocino.
- Over the next 9 decades, relative sea levels are expected to rise both south and north of Cape Mendocino, although somewhat less to the north.
  - By 2030 (relative to 2000):
    - South of Cape Mendocino: 4 to 30 cm (1.5 inches to 1 foot)
    - North of Cape Mendocino: -4 to 23 cm (-1.5 inches to 9 inches)
  - By 2050:
    - South of Cape Mendocino: 12 to 61 cm (5 inches to 2 feet)
    - North of Cape Mendocino: -3 to 48 cm (-1 inch to 19 inches)
  - By 2100:
    - South of Cape Mendocino: 42 to 167 cm (17 inches to 5.5 feet)
    - North of Cape Mendocino: 10 to 143 cm (4 inches to 4.7 feet)

Sea level rise will accelerate the erosion of cliffs and bluffs. Existing coastal armoring, which currently covers approximately 10 percent of the California shoreline, was designed for the prevailing wave heights and wave energies at the time. Wave heights and energies may increase with sea level rise, and eventually inundate those armoring systems. The major concern, however, is when high waves occur at times of high tides. If the frequency or intensity of storminess changes as a result of climate change, the frequency of high sea level extremes also would likely change. Even if the storminess regime does not change, sea level rise will increase
the exposure of the coast to storm-driven surge and high waves, magnifying their impact on the coast. If left unmanaged, beaches and unconsolidated cliffs and bluffs will migrate inland at a rate that is greater than at the present. The expected management response will be to enhance the armoring to meet new sea level conditions, or to accept retreat and loss of the cliffs and bluffs. Where armoring is placed, beaches will eventually disappear. Without an adequate supply of sediment, beaches and dunes provide little protection to cliffs and bluffs from increased wave heights. The 2009 Pacific Institute study found that:

- The Central and Northern California coast is projected to lose 41 square miles of land by 2100 with a 1.4-meter sea level rise.
- Estimates of the effects of erosion from sea level rise show that cliffs will erode an average distance of 66 meters (216 feet) by 2100, and dunes will erode an average of about 170 meters (558 feet).
- 110 miles of railroad, 250 miles of highway, and 1,500 miles of roads are vulnerable to a 1.4-meter rise in sea level.
- A 1.4-meter rise in sea level will put 480,000 people at risk of a 100-year flood event, given today’s population. The cost of replacing property at risk of coastal flooding is estimated to be nearly $100 billion (in 2000 dollars). The estimated costs of building seawalls and bulkheads to protect some vulnerable areas are at least $14 billion with added maintenance costs of $1.4 billion per year.
- Approximately 10,000 parcels, with an economic value estimated at $14 billion, are within the expected erosion zone.

Marshes, mudflats, and wetlands are at serious risk of destruction due to higher sea levels. Marshes and wetlands provide protection from storm surges and flooding. Without an adequate sediment supply, those protections may be lost. Entrapment of sediment behind dams makes beaches and wetlands/marshes less likely to survive. For wetlands/marshes to survive in 2100, they will either need to be able to migrate inland or have an adequate sediment supply to vertically keep pace with sea level rise.

Uncertainty exists in the predictions of local sea level rise presented above, primarily because of uncertainties regarding future ice losses, constant rates of vertical land motion, ocean dynamics, and the need to make assumptions about the conditions that drive the ocean models for global sea level rise (e.g., input data for models such as population growth, technological improvements, large volcanic eruptions). The uncertainties are reflected in the ranges of sea level rise shown above. The National Research Council report noted that confidence was high for 2030 and perhaps 2050. For 2100, the confidence was only that that sea level rise will fall within the uncertainty bounds. The authors of this report conclude that the message is clear:

*The California shoreline will experience a rise in the level of the seas. There will be significant impacts to physical, biological, and economic resources along the shoreline and inland bays, primarily due to erosion of dunes, beaches, and cliffs/bluffs, loss of marshes/wetlands, flooding, increasing salinity in estuaries, and changing habitats for animal and plant life.*
The Social and Economic Impacts of Erosion and Accretion along California’s Shoreline

To understand the economic and social implications of erosion and accretion along the California coast, it is important to consider the geographic context for these impacts. In California, three-quarters of the 1,100-mile shoreline consists of high cliffs and bluffs, often fronted by sandy beaches. California’s shorelines are a critical resource for the State’s economic and social wellbeing. If coastal features like beaches and bluffs were unused and uninhabited, erosion would have little economic or social consequence for California. Residents and tourists flock to beaches to recreate (e.g., surf, jog, bird watch, swim), the shoreline is well-developed with expensive homes and commercial establishments, and numerous businesses depend on resources accessible from the shoreline (e.g., fishing, boating, mineral extraction, shipping).

Recreational and commercial uses generate substantial revenues for local communities and the state. In 2013, these uses generated over $44 billion. Additionally, the coast is the most popular place to live and work. Approximately 80 percent of Californians live within 30 miles of the coast and three of the ten most populous cities in America are located on California’s central and southern shores (Los Angeles, San Jose, and San Diego).

Although California has the largest ocean economy in the nation, the combination of population, coastal processes, and economic activity tends to focus the discussion of economic and social impacts in the central and southern regions of the state. The ocean economies of all three regions (northern, central, and southern) rely heavily on recreation and tourism and marine transport, which combined account for over two-thirds of GDP and 95 percent of ocean sector employment. However, the regions exhibit differences in total employees, wages, and gross domestic product within their respective ocean sector economies.

**Recreation:** Beaches host a variety of recreational uses that can be affected by a changing shoreline. Erosion usually narrows beaches, which can limit access, the number of users, and the overall quality of the beach experience. Beach nourishment and shoreline armoring are common responses to erosion, and user groups are very engaged in the decision-making process to determine the most appropriate response. The surfing community in particular is actively involved in shoreline management issues, especially in the central and southern parts of the State.

Climate and water temperature make Southern California a popular place to live, visit, and go to the beach. These favorable conditions may contribute to that region’s ocean economy being more than $10 billion larger than that of the northern and central regions combined ($27 billion versus $16 billion in 2013). Moreover, the social and economic impacts of erosion and accretion are better documented for the central and southern shorelines of the State, which host year-round beach recreation, three of the top-ten largest U.S. ports, and much of the State’s population. Along the northern shoreline, there are few documented social and economic impacts because of sparser development and fewer recreational opportunities. The dearth of documentation suggests that there are fewer social and economic impacts of erosion and accretion along the northern shoreline.

**Social Impacts.** Social impacts occur when societal benefits are directly affected by erosion, such as loss of beach quality (e.g., area, sand quality, and wave quality) and associated recreational uses, loss of private property, and damage to public infrastructure. There are few documented social impacts of accretion along ocean-facing shorelines in California, although accretion commonly affects navigation channels along
sheltered shorelines by restricting access through the mouth of bays, inlets, and harbors, which requires periodic dredging. Dredging and disposal of dredged material is not without issue. Public concerns regarding disposal of contaminated dredged material have been a significant issue for many dredging projects in California.

This study also found that social impacts are often manifested in response to the methods undertaken to control shoreline change. Shoreline management practices bring to the surface social and economic conflicts because of the trade-offs between public and private interests as well as the trade-offs between users within these sectors and their perceptions of how shoreline management methods best serve their interests.

Beach recreation is a large part of California’s economy and is also a large part of the social fabric of daily life, especially for Southern Californians. Social impacts are more difficult to quantify than economic impacts and are best illustrated through case studies included in Section 7 of this report. Those case studies illustrate the social challenges that have arisen in managing changing shorelines. They often show that measures undertaken for one purpose may be incompatible with other purposes. Some of the social impacts include:

- **Public beach access blocked or reduced by shoreline armoring.** Exemplified in the Broad Beach case study, shore-parallel armoring installed to protect infrastructure or private property can prevent the public from accessing the beach. In California, private-property owners have clashed with the general public over access issues for decades. The State is mandated to protect public access to the shore (Article X Section 4 of the State Constitution, California Coastal Act).

- **Loss of beach recreational opportunities.** Surfing experiences, as illustrated in two case studies, can be altered by structures built perpendicular or parallel to the shore. In some locations, jetties are known to provide better waves for surfing. One case study showed that recreational losses can be reversed; Santa Cruz County saw an increase in beach attendance when riprap was removed from the beach and replaced with a bluff stabilization method, which improved aesthetics and beach access.

- **Aesthetic impacts.** Ocean Beach (San Francisco) and Pleasure Point (Capitola) are two examples of many along the California coast where armoring responses may diminish the quality of the public’s beach experience. Rubble from damaged seawalls or riprap can be unsightly and can interfere with or otherwise detract from views both from the water and on the beach. Federal, state, and local agencies are helping to mitigate this issue, but more aesthetically pleasing options for erosion control are not always feasible.

**Economic Impacts.** Quantification of costs attributable to shoreline erosion control, specifically beach nourishment, and to a lesser extent, shoreline armoring, were the two primary costs of shoreline change examined in this report, and the two most common responses in the State of California. Tabulation of expenditure information for these approaches involved a number of challenges, and this report acknowledges several obstacles in attempting to calculate the total costs of managing shoreline change.
Information is not generally available on the costs of alternative strategies, the costs of retreat, and the cost of abandonment strategies.

Despite these challenges, the costs of shoreline change in California (based on the information gathered) can be summarized as follows:

- **Costs of shoreline hard armoring** (borne by private-property owners and local and state government): With over 10 percent of California’s shoreline armored (136 miles of seawalls), a rough estimate of construction costs for armoring falls somewhere in the range of $350 million to $7 billion (or $3 million to $53 million per mile), not including reconstruction or maintenance costs or the costs of secondary impacts. Costs of armoring, which are estimated to be about $500 to $10,000 per foot, depend on the characteristics of the local site.

- **Costs of nourishment** (borne by local, regional, state, and federal government): From 1984 to 2010, the State spent more than $67 million to nourish California’s beaches according to the California Department of Boating and Waterways (2011). The USACE has expended $48 million on nourishment projects since 1990 (USACE Los Angeles and San Francisco Districts 2012) for estimated total beach nourishment cost in the State of at least $115 million since 1984.

Environmental Implications of Erosion and Accretion along the California Shoreline

Sediment flow in coastal areas is a complex process that affects the physical environment, marine life, and human communities along the coast. The California coastal environment contains diverse habitats, including wetlands, estuaries, kelp forests, seagrass beds, mudflats, cliffs, sandy beaches, and dunes. These areas provide important habitat to a variety of plant and animal life. At the same time, increasing pressure on coastal areas from human activity (e.g., development and recreation) is having profound impacts on the natural cycles of sand and sediment distribution in the coastal habitats.

Sediment can have both beneficial and undesirable impacts. Sediment is an important resource to maintain and restore beaches and coastal habitats, such as marshes, wetlands, and mudflats. However:

- Too much sediment can damage habitats, interfere with the food chain, and cause obstructed channels, river overflow, smothered reefs, and high turbidity that blocks sunlight; and

- Too little sediment can lead to disappearing beaches and other eroded coastal features such as saltwater marshes, with significant implications for aquatic and terrestrial habitat for a wide variety of species, potentially reducing the abundance and biodiversity of such animals as fish, turtles, and birds.

As would be expected, the impacts on the environmental resources along the California shoreline vary with such factors as climate, shoreline features, and wave energy. For example, changes in habitat due to erosion impact bird populations differently on the rugged north shoreline than on the Southern California beaches and bluffs.

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2 The California Department of Boating and Waterways is now (2013) the Division of Boating and Waterways under the California Department of Parks and Recreation
Habitat loss and its effect on biodiversity is a growing problem in California (and around the world). The health of coastal environments depends on the conservation of a diversity of coastal habitats that provide shelter, food, breeding grounds, nursery areas, migratory corridors for marine life, store water, buffer water quality, and resist storm-related erosion. An adequate supply of sediment is key to conserving these habitats.

**Effects upon Wetlands and Salt Marshes.** The effects of erosion on wetlands and salt marshes can be positive or negative depending upon the local topography and the need for sediments to maintain the balance. Wetlands and salt marshes can be quite resilient and adapt to changing conditions. Wetlands and salt marshes provide an array of ecosystems services contributing to the economy and social well-being. Commercial and sport fisheries along the coast depend upon wetlands to serve as the nursery for spawning, foraging, and cover for small fish as they grow. Birds depend upon wetlands for migratory resting places, breeding and feeding grounds, and cover from predators. Wetlands serve as filters for nutrients and sediments, and help to control issues of sedimentation, eutrophication, and water quality problems in bays and coastal waters. Other well-known functions of wetlands that can be impacted by erosion and accretion include:

- Flood mitigation. Wetlands temporarily store floodwaters, release water slowly into the system, and reduce flood peaks and surges;
- Recreational opportunities, including fishing and hunting;
- Potential for educational opportunities, serving as outdoor classrooms;
- Aesthetics and opportunities to experience nature; and
- Enhancing the value of adjacent properties.

**Effects of Turbidity and Sedimentation.** Erosion and accretion are associated with elevated levels of suspended sediment in the water and an increased amount of sediment settling on the seafloor.

- Excessive turbidity, caused by fine-grained sediments and colloidal materials, degrades water quality and increases morbidity among marine life. Higher turbidity increases water temperatures as suspended particles absorb heat, as well as reduces the concentration of dissolved oxygen. Increased turbidity also reduces the amount of light penetrating the water, which reduces photosynthesis and can have harmful impacts on estuaries, wetlands, kelp forests, eelgrass, and surfgrass. A number of studies found that birds avoided waters with increased turbidity, expressing a preference for clearer waters.
- Increased sedimentation can blanket the sea floor and smother fish eggs. When particles settle, they can smother bottom-dwelling benthic invertebrates. Non-burrowing substrate organisms, submerged aquatic vegetation, and shell reefs (oysters) may be hardy enough to withstand some level of sedimentation, but if they are impaired, the recovery time is long and populations are difficult to re-establish.

**Effects of Erosion Management—Beach Nourishment.** There can be unintended negative environmental consequences from beach nourishment projects on the beach or in the sand borrow area, including short-term disturbance of the indigenous biota of the beach (e.g., by smothering with new sand or with
incompatible material); impacts to the food web (potential to alter habitats or adjacent areas used by species for nesting, nursing, and breeding); environmental impacts in the subtidal area, such as increased turbidity; and impacts to the biota in the sand borrow area. Turbidity effects in the subtidal area can include negative effects on sea bottom vegetation from light reduction, interfere with foraging or migration of sensitive species from reduced water clarity, or result in sub-lethal (e.g., larval growth, feeding) or lethal stress to fishes or invertebrates. The recovery is generally in a year or less, especially when sand is placed on sand-starved beaches with limited habitat functions.

Summary Note on Environmental Effects of Erosion and Accretion. Erosion and accretion are natural processes, have been ongoing for years, and can provide benefits for beach, dune, and marsh nourishment. Or, they can have negative effects on fisheries and other wildlife through direct impacts, disappearance of habitat, and damage to primary food sources. The questions for coastal managers relate to the human-induced changes to the natural erosion and accretion cycles that habitats, fish and wildlife populations cannot tolerate.

California’s Systematic Approach to Sediment Management

The USACE and the California Natural Resources Agency are co-chairs of the California Coastal Sediment Management Workgroup. The California Coastal Sediment Management Workgroup is leading the effort to change the paradigm for considering sediment and erosion issues from the traditional project-by-project approach to a more systematic and broad view of sediment as a resource.

To tackle the current and coming problems of erosion and sediment issues along the California shoreline, the California Coastal Sediment Management Workgroup prepared a Sediment Master Plan, as a living document. The Sediment Master Plan (latest update is June 2012) is a 15-year process to identify information needs, challenges, and actions needed to systematically approach sediment management along the shoreline. The Sediment Master Plan includes a compilation of tools, outreach actions, strategies, and informational reports designed to assist and guide sediment managers and others to systematically implement sediment management throughout the California coast. A key element in the Sediment Master Plan is to identify and plan for use of dredged material in a beneficial manner.

Major progress is being made at the federal, state, and local levels to assess sediment transport; identify inconsistent regulations and policies; and address economic, social, and environmental local issues associated with coastal sediment management. The California Coastal Sediment Management Workgroup
has produced a number of critical documents, computer-based tools, and outreach materials. In addition, sediment management plans for specific shoreline areas have been completed for southern Monterey Bay, Santa Barbara and Ventura Counties, Orange County, and San Diego County. Others are in progress. Implementation of those completed plans is underway with first steps including preparation of programmatic environmental impact assessments.

**Systematic sediment management:** California is committed to developing regional sediment management plans for its entire shoreline. The Coastal Sediment Management Workgroup, created in 1999 and co-chaired by the USACE and the California Natural Resources Agency, is a unique intergovernmental collaborative partnership leading these efforts.

**Conclusions**

California’s shoreline is eroding, and the social, economic, and environmental implications are enormous. Natural factors influencing erosion include El Niños and the Pacific Decadal Oscillation. Human influences include reductions in sediment supply caused by the construction of dams and armoring cliffs, and construction of structures to protect widened beaches. In essence, there are no longer any natural beaches left in California. Beach nourishment, to widen what would have been naturally narrow beaches, generally results in the continuing need for nourishment and is a distinct contributor to the perception that beaches in Southern California are eroding.

Sea level rise will accelerate the erosion process and complicate the short- and long-term management response to address the serious social, economic, and environmental issues associated with erosion of beaches, cliffs/bluffs, and wetlands. Existing federal, state, and local policies, procedures, and regulations should be reviewed and updated.

To address the complex issues associated with erosion and accretion, the systematic and inclusive approach embodied by the California Coastal Sediment Management Workgroup and local organizations is critical to the current and future health of the California shoreline.
Report Organization

The report is organized as follows:

- First, the physical processes influencing the shoreline are described. This includes a brief summary of what is known about erosion and accretion on the California shoreline, including sediment budgets, and descriptions of shore protection measures that have been used to date, such as armoring and beach nourishment.
- Next, a summary is provided of what is currently known about sea level rise and the implications for the California shoreline.
- This is followed by the results of an assessment of the economic and social impacts of shoreline change caused by erosion and accretion.
- Then, the environmental and ecological resources along the shoreline and the potential implications of erosion and accretion on those resources are presented.
- Next, the efforts, successes, and challenges of federal, state, and local entities are described in addressing the shoreline issues caused by erosion and accretion (Figure 1). Local governments have banded together in a number of local collaborations to jointly work toward solutions. Federal, state, and local governments and non-government organizations are working together in the California Coastal Sediment Management Workgroup to address the issues in a systematic manner.
- Fifteen case studies are then presented that demonstrate the complexities of shoreline management issues and the variety of situations that need to be addressed.
- Finally, findings and conclusions are listed.

![Figure 1. Road erosion along Highway 1.](https://www.californiacoastline.org)

This figure shows erosion along the highway, a section of California shoreline with an eroding cliff, narrow beach, threatened roadway, and a temporary fix. This is typical of the range of challenges that federal, state, and local government entities are addressing. Source: Kenneth & Gabrielle Adelman, California Coastal Records Project 2002. [www.californiacoastline.org](http://www.californiacoastline.org)
2. CHANGES ALONG THE CALIFORNIA SHORELINE

Erosion and accretion along the 1,100-mile long California coast, particularly in the southern part of the State, have significant economic, social, and environmental impacts on the region and the nation. Erosion affects a variety of activities that are critical to society and the economy. A combination of factors such as storms, man-made structures, sea level rise, and sediment deficits can cause erosion. Accretion is usually considered in a positive manner to maintain beaches and recreational opportunities, provide habitat for shorebirds, and build or maintain marshes. Accretion can also negatively alter fish and shellfish habitat, affect wave breaks, and impede navigation by decreasing channel depth in harbors and bays.

To understand the economic, social, and environmental implications of erosion and accretion along the California shoreline, it is important to first consider the geographic context for these impacts, a combination of direct and indirect forces that include tectonics, waves, and wind. The anthropogenic influences are also important on the natural availability of sediment and the shoreline management practices currently in place.

Geological Setting of the California Shoreline

The present-day configuration of the California coast formed as a result of millions of years of interactions between the Farallon and Pacific plates (made of oceanic crust) and the North American Plate (made of continental crust). For the past 300 million years until around 25–30 million years before the present, the tectonic framework of the entire California shoreline was that of a collision (Davis and FitzGerald 2004; Hayes and Michel 2010; Inman and Nordstrom 1971; Schwartz 2005) or tectonic coast (Hayes 1964, 1965). At that time, the entire State of California was located along a convergent plate boundary where the dense and heavy oceanic crust of the Farallon plate was subducted below the leading edge of the lighter continental plate (Figure 2). The result was uplift and the formation of young mountain ranges along the coast (Harden 1997; Hayes and Michel 2010). This is why the majority of the western coast of the North America is dominated by geologically young and high mountain ranges from recent orogenic activity, mostly young sedimentary and volcanic rocks.

Presently, California is only on a true collision coast north of the Mendocino triple plate junction near Cape Mendocino to the Oregon border (Hapke et al. 2006). The plate fragment currently subducted is often referred to as the Gorda Plate or the southernmost portion of the Juan De Fuca Plate (Figure 2). The Gorda plate is what is left of the mostly subducted Farallon Plate (Hayes and Michel 2010).
Figure 2. Tectonics of the California Shoreline. Simplified schematic showing the present-day convergent boundary north of the Mendocino triple plate junction where the Juan de Fuca (or Gorda) Plate is being subducted beneath the western edge of the North American Plate. The mountains of the southern Cascade Volcanic Arc in the Shasta Cascade area of Northern California (e.g., Mt. Shasta and Lassen Peak) were formed over the past 35 million years in the over-riding continental crust and continue to remain active today.

Tectonic activity along the coast south of the Mendocino triple plate junction is now dominated by lateral movement associated with the San Andreas Fault Zone (Hapke et al. 2006; Hayes and Michel 2010). Approximately 28 million years ago, the plate boundaries changed from convergent to transform where the Pacific Plate joined the North American Plate (Cole and Basu 1995). Transform faults, like the San Andreas Fault, form where two plates slide past each other on strike-slip faults, and no lithosphere is lost or gained (Christiansen 2009).

Even though the present-day central and Southern California coasts are not strictly collision controlled because they continue to be dominated by rapid tectonic uplift, they still generally fit the characteristics of a collision or leading-edge coast model (Hapke et al. 2006).

Characteristics of California’s coastal tectonic framework broadly include:

- Mountainous shorelines and beaches backed by wave-cut sea cliffs
- Steep, narrow continental shelf (much narrower than the Atlantic shoreline of the U.S.)
- Large waves that move from deep water to onshore relatively quickly
- High wave energy—especially in Northern California where the coast is more exposed to North Pacific storms—causing cliff erosion, rapid sediment reworking, and pocket beaches
- Erosional—young sediment coming from mountains having temporary residence in the coastal zone before moving off the shelf
• Transport—sand movement along the coast by waves and currents within the surf zone until it is moved offshore to the deep ocean
• Lateral movement of sediment (i.e., compartmentalized)
• Volcanism, earthquakes
• Principal sources of sediment for each littoral cell, rivers supplying large volumes of sandy material
• Lack of major deltas
• Relatively few marshes, wetlands, and barrier islands compared to eastern seaboard

California’s Climate

California’s coastal climate is highly variable. Certain parts of Northern California experience well over 50 inches of rainfall per year (e.g., the coastal ranges in Eureka) (Griggs et al. 2005). The southern end of the coast is essentially a desert and places like San Diego only receive around 10 inches per year (Griggs et al. 2005). Storms that deliver the majority of the rainfall tend to be concentrated during the winter months and cause the most devastation from erosion. Significant erosion occurs when large winter storms and storm surges coincide with very high tides, particularly during El Niño years when the sea level is usually higher than normal. This combination can result in cliff/bluff failures and or damage to oceanfront properties and infrastructure. During the summer months, beaches will be built back up from more gentle waves and weather.

Most storms in California originate in the northwest off the coast of Alaska and the Aleutian Islands (Griggs et al. 2005; Harden 1997). These storms can be severe in California’s northern coast generating waves as large as 20 to 30 feet offshore (Griggs et al. 2005), and their tracks or paths can be influenced by other factors like the North Pacific High and El Niño.

The North Pacific High is a large air mass that has a strong influence on California’s coastal weather patterns (Griggs et al. 2005). The North Pacific High varies seasonally and moves north to around San Francisco during spring and summer when it receives more solar energy. In the winter, the North Pacific High moves further south to around 20° north latitude off the coast of Mexico (Griggs et al. 2005). These movements and the exact position of this air mass are unpredictable and can change each year, but can have a pronounced effect on California’s climate.

In the summer, the high pressure of the North Pacific High has a sheltering effect for the California coast and will weaken storms heading from the west or redirect them north towards Oregon and Washington. In the winter, the North Pacific High moves south of California and large storms that come from the Pacific Ocean are able to reach the coast (Griggs et al. 2005).

Storms also can originate from the western Pacific Ocean. Sometimes these storms will pick up moisture in the tropical Pacific Ocean in the vicinity of the Hawaiian Islands and move towards Southern California. Cyclones can approach from the south, and occur infrequently during the summer and fall. The last major cyclones to reach the southern coast of the State were in 1988, 1982–83, and in 1939. While rare, these storms can cause extensive wind and wave damage, especially to coasts that are angled south such as Long Beach or Laguna Beach (Griggs et al. 2005). The largest storms in California happen during El Niño events.
The California Shoreline and Coastal Physical Processes

The Shoreline

The California coast can be divided into three categories:

1. Steep coastal mountains and sea cliffs with hundreds of feet of elevation
2. Uplifted marine terraces and sea cliffs from ten to several hundred feet high
3. Coastal lowlands with beaches, sand dunes, and lagoons.

About 790 miles of the 1,100-mile shoreline are actively eroding sea cliffs, of which 650 miles are lower relief cliffs and marine terraces (Griggs et al. 2005).

The southern and northern coasts can be divided into two distinct physically dissimilar regions. The boundary occurs at Point Conception, where both the coastal alignment and the physical environment change abruptly. The Northern California shoreline is fully exposed to winter storm waves generated in the North Pacific, while the Southern California shoreline is afforded partial shelter from these waves by Point Conception and numerous offshore islands.

- South of Point Conception, the shoreline typically is backed by coastal plains and marine terraces. Expansive sandy beaches dominate, as in Santa Monica Bay, although they may be separated by rocky headlands such as the Palos Verdes Peninsula.
- The Northern California shoreline tends to be more rugged. At many locations, the mountains extend to the shoreline with only a narrow sliver of sand at their base. Prominent headlands interspersed with stretches of sea cliffs and small pocket beaches are common. Some areas, such as Big Sur, contain rocky bluffs and outcrops with relatively few beaches (CSMW 2010).

For this California Regional Assessment, the shoreline north of Point Conception is divided into the central and northern shoreline sections, based on a number of factors described below. The central region is from Point Conception to Point Tomales and the northern region is from Point Tomales to the Oregon border.  

Coastal Physical Process—Tides

The extent of tides are caused by a combination of three processes: 1) the gravitational pull of the moon and sun on the oceans, 2) wind set-up (when wind raises the level of water upwind or lowers it downwind); and 3) storm surges (Hayes and Michel 2010). In California, wind set-up can be a significant factor in raising water levels to a degree that can cause increased erosion. For example, strong southerly winds can cause what would be a low tide to extend as far as a regular high tide (Hayes and Michel 2010).

Tides are mostly mixed semi-diurnal tides (having two tidal cycles each day); these tend to be at four different levels and are often referred to as higher high, lower high, higher low, and lower low tides (Hayes and Michel 2010). The daily tidal cycle is 24 hours and 52 minutes (Shepard and Wanless 1971).
Tides also will have a maximum tide each month (or spring tide) associated with the full and new moon, a minimum tide (or neap tide) during the first and third quarter of the month.

In California, the tidal range is generally about 3 to 5 feet (Hayes and Michel 2010), except Spring tides vary along the coast up to almost 11 feet. In 2013 for example, they were predicted to be around 9.3 feet in San Diego, 8.0 feet at Point Arguello in Central California, 8.8 feet in San Francisco Bay at Alcatraz, and 10.7 feet in Humboldt Bay (NOAA 2006).

**Coastal Physical Process—Waves**

All ocean waves are generated by an energy source, primarily winds blowing over the surface of the water. Submarine earthquakes and landslides can also produce significant energy and therefore result in unusually large waves such as tsunamis; their occurrence is rare (Easterbrook 1993; Harden 1997). Waves generated by wind are responsible for most erosion and deposition along the California shoreline. The dominant waves that break along the coast in California are often “swell” waves that are generated far offshore.

**BOX 2. SWELL WAVES**

Swell waves are ocean waves generated from a distant source, such as a storm system, and not raised by the local wind blowing. Swells characteristically exhibit smoother, more regular and uniform crests, and a longer period than local wind waves. Swell waves can travel great distances with very little energy loss. It is not unusual for swells that hit California beaches to be generated near Australia. The period between swells, the wave length, is generally 10 to 18 seconds for long-period waves, whereas the swells on the East Coast are in the range of 6 to 8 seconds (Shepard and Wanless 1971).

From north of Point Conception to the Oregon border, the coast generally experiences more severe wave conditions than to the south. Also, north of Point Conception, the continental shelf is relatively narrow with a quick drop off from the beach. This means even large waves will arrive close to the shoreline before breaking (Harden 1997). Moving south and east of Point Conception to the Mexican border, the position of the shoreline no longer directly faces the weather, and several offshore islands reduce the impact of storms and wave energy (Norris and Webb 1990).

The most significant waves that approach the California coast are those generated by winter storms in the northern Pacific Ocean near the Gulf of Alaska. During the late summer and fall, storms from the south off Baja California and the Mexican mainland also can cause large waves (Harden 1997).

As waves approach the shoreline, they bend and slow down when reaching shallow depths. This process is known as refraction. As waves refract, their crests line up with the bottom contours causing a gradual alignment that is more parallel to the shoreline causing a longshore current (Bascom 1964, 1979; Dean and Dalrymple 1991, 2004; Komar 1976; Schwartz 2005). Despite this tendency, waves most often break at an oblique angle to the shoreline.
1. Waves also refract when they reach irregular shorelines such as the headlands and pocket beaches commonly found along the California coast (Figure 3). That wave refraction causes more energy to be focused on the small surface of prominent headlands, while beaches and bays have more quiet waters. This is why headlands that protrude into the ocean will experience more intense erosion and are characterized by steep cliffs, powerful waves, and rocky shores. Over time, erosional processes lead to a straightening of the shoreline (Harden 1997).

**Box 3. Breaking Waves**

In deep water, only the wave form moves, but when waves arrive in shallow water, both the wave form and the water move. Although not obvious to an observer, a wave extends below the wave trough to a depth that is one-half the wavelength. This depth is called wave base, below which no water motion attributable to surface waves occurs.

Waves behave differently once they enter shallow water (water depth < 0.5 wave length), the depth at which wave base is intercepted by the seafloor. Friction slows the water motion near the wave base, but water at the wave crest continues to move at the same speed and the water begins to pile up at the surface. This continues until the wave height is one-seventh the wave length (or when the water depth is about one to two times the wave height). At this point the wave can no longer support itself, and the wave breaks. Waves can also break if the wind grows strong enough to blow the crest off the base of the wave. The piling up and breaking of water within the surf zone generates a horizontal movement of water.

Importantly, the deeper water is off a shoreline, the further into shore waves can move before they begin to "feel bottom" and break. Erosion along a shoreline will tend to be greater if relatively deep water is found immediately offshore. In contrast, a wide beach results in waves breaking far offshore and the expenditure of wave energy moving beach sand around rather than eroding a dune, bluff, or cliff.

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http://faculty.gvsu.edu/videticp/waves.htm

**Figure 3.** Wave refraction along an irregular shoreline of headlands and pocket beaches. Arrows demonstrate how wave energy is distributed along different shoreline features. Source: Easterbrook 1993
Coastal Physical Process—Longshore Currents

Most waves approach the beach at an angle as a result of refraction. The water returns down the beach face at right angles to the angle of the approaching waves. This causes a flow of water away from the incoming waves, which creates a current parallel to the shore known as a longshore current (Figure 4). These currents are responsible for the natural process of longshore transport or littoral drift, which is the movement of sand along the shore in a zigzag pattern.

In addition to transporting sand along the beach, longshore transport may cause erosion in some areas and accretion in others. Often, this becomes a major problem where manmade structures, such as jetties, interrupt longshore transport. This frequently results in the need for sediment bypassing (i.e., pumping sand from the updrift side of a jetty to the downdrift side) or artificial beach nourishment to make up for the disruption to the natural sediment movement patterns.

The direction of the longshore current flow may change throughout the day as the wave approach changes, but in most areas, there is one dominant direction for the longshore current and resulting net sediment transport (Pinet 2003). The majority of waves in California come from the northwest; therefore, the dominant direction of longshore transport is from north to south for most of the coast north of Point Conception. South of Point Conception, the shoreline bends, and sand is carried east and then southeast with a few localized exceptions (Harden 1997).

The strength of the longshore current and wave action are significant factors in determining the amount of sand transported, but the sediment composition of the beach also will affect this movement. Smaller particles, such as mud (silt and clay) and sand, are suspended in water longer and do not settle as easily as larger particles, such as gravel. Thus, even weak currents can move small particles and result in some sediment movement. Sand and larger particles remain in the active surf zone while currents and wave energy cause the finer material to move offshore. It is important to consider both the energy conditions at the site of deposition and the sediment size distribution to determine sand movements (Pinet 2003).

Longshore transport directly influences:

- Dredging requirements: deposition and shoaling in open-coast channels and updrift of coastal structures; placement of dredged material for nourishment of beaches.
- Beach condition: understanding long- and short-term erosion and accretion trends.
- Coastal projects: designing structures and beach fill to mitigate for coastal storm damage, and designing inlet structures to better operate and maintain channels.
Figure 4. Longshore currents. 
Illustration of longshore current that results from waves coming in at an angle to the shoreline. Subsequent net movement of sand grains in the direction of longshore current is known as longshore transport or littoral drift.

Erosion of the California Shoreline: Natural and Anthropogenic Causes

A significant portion of the California coast is actively eroding. Being a natural process, erosion along the California shoreline has been substantially altered by human activities in changing the movement of sediment as well as drastically reducing the natural supply of sediment to the shoreline. Harbor jetties, groins, and breakwaters interrupt the natural transport of sand along the shoreline. Dams, sediment traps (i.e., dredged channels and harbors), channelized rivers and streams, hardened shorelines, land areas covered with impervious surfaces (i.e., urbanization), and in-stream sand mining have all combined to substantially decrease the supply of beach-compatible sediment provided to the shoreline (Beach Erosion Survey 2010). Figure 5 provides a summary of natural and anthropogenic causes of erosion, and Figure 6 provides a simple visualization of human-induced changes to natural sediment deposition.

Factors affecting erosion

The primary factors that influence the severity and extent of erosion of the shoreline include:

- Frequency and intensity of winter storms, and wave characteristics;
- Tidal level during storms or when exposed to swell waves (A larger tidal range will greatly increase the surface along the coast that can be attacked by waves. Along the California coast, the tidal range is 5 to 10 feet5);
- Exposure/orientation of the shoreline to the storm wave regime;

5 NOAA http://tidesandcurrents.noaa.gov/; see also discussion on Tides
• Local topography: beaches, cliffs, bluffs, natural coves;
• Bathymetry: the slope to the shoreline (Deeper water along the shoreline allows waves to attack the beaches and bluffs and cliffs, whereas shallow waters and beaches can dissipate some of the wave energy before they hit the shoreline);
• The erodibility of the shoreline materials: beach sand and unconsolidated sediments versus rock; and
• Anthropogenic structures: hardened shorelines, breakwaters, groins, and jetties.

Erosion rates for sea cliffs depend on the intensity and frequency of storms, wave height or energy, and various properties of the rocks or sediments that compose the cliff. For unconsolidated bluffs and cliffs, natural coastal weathering processes (e.g. chemical weathering by seawater and sand abrasion) are worsened by human impacts (e.g. runoff from storm drains and landscape watering) that weaken cliffs. Such activities make cliffs more susceptible to slumping. Many native plants on the bluffs can act as stabilizing factors. However, non-native plants which are commonly found along unconsolidated bluffs, can have the opposite effect.

**FACTORS AFFECTING SEDIMENT PRODUCTION**

![Diagram showing factors affecting sediment production](image)

**Figure 5.** Factors affecting sediment production.

*Source: Grandy and Griggs, Shore & Beach Winter 2009*
Erosion of the California Shoreline: Shoreline Management Practices

Shoreline management practices are generally categorized as (1) hard structures, (2) soft structures, and (3) non-structural measures. Hard structures are permanent works that either armor the shoreline to prevent further erosion landward of the structure or interrupt the lateral movement of sand to lessen beach erosion via groins, breakwaters, or jetties. Soft protection practices utilize natural resources and systems to maintain the shoreline, such as beach nourishment. Some coastal management projects combine both hard and soft stabilization techniques to address problems in the coastal zone. All areas utilize non-structural approaches (i.e., plans, policies, and regulatory measures) to some extent to manage or restrict human activity along the shoreline and protect beaches. These three types of management practices are described below. The USACE Coastal Engineering Manual provides additional information on hardened methods of shore protection⁶.

Hard structures—armored shorelines

Historically, the common solution to prevent shoreline erosion was to construct engineered hard structures that were resistant to erosion and could absorb some of the wave energy reaching the shore. These structures often have many deficiencies as a result of a lack of historical data when constructed, inadequate knowledge of coastal processes, and disruptions to the natural sediment transport system. All of those can cause erosion of the areas the structures are meant to protect. In the early 2000s, around 110 miles or 10 percent of the State’s entire coast were considered to be armored (Griggs et al. 2005). In Southern California’s four most urbanized counties (Ventura, Los Angeles, Orange, and San Diego), 33 percent of the 224 miles of shoreline have now been armored (Griggs 2005, 2010).

Hard structures frequently have unintended consequences. For example, armoring of coastal cliffs and bluffs (e.g., seawalls, revetments, rip-rap) are meant to protect the cliffs and bluffs and the property atop them. Impacts of armoring include (Griggs 2005):

- Negative visual and aesthetic impacts,
- Beach access is sometimes affected,
- Loss of beach width on which the armoring is placed,
- Loss of sand supply from the eroding cliffs and bluffs,
- Passive erosion will result in a gradual loss of beach in front of the armoring, as the shoreface on either side of the armoring continues to migrate inland, and
- Active erosion and the potential impacts on the beach itself and impacts on the downcoast end of the armored section.

The California Coastal Commission is now reluctant to allow any seawalls or hard structures to be built, but emergency permits are often granted if a structure is in imminent danger. To apply for a coastal armoring permit, the application must include engineered plans, a strong justification, an environmental impact report, and consideration of alternatives.

Visual impacts are an obvious and irrefutable result of coastal armoring, a process which began in California decades before the coastal zone management program existed. Thus, even as lower-impact armoring technology has advanced, there are still instances where older seawalls remain in place and require ongoing maintenance. Seawalls and other types of armoring, such as rock revetments or riprap, can negatively affect the public’s beach experience by interfering with the natural landscape, and in some cases, reducing access to the beaches. California has recently seen advancements in coastal armoring techniques that can minimize the visual impacts to the beachgoer (Figure 7). Shotcrete, or sprayed concrete, has been used to mimic natural bluffs as one, rather expensive, way of considerably reducing visual impacts (Griggs 2010). Although this method provides a solution to the visual impacts associated with bluff stabilization, riprap, and other less aesthetically pleasing armoring techniques are still used (see Ocean Beach Case Study). A recent study in Santa Barbara and Ventura Counties found that seawalls, revetments, and groins have neither a negative or positive effect on the beach experience (Sterrett 2013), possibly indicating changing attitudes or more refined survey techniques.
The California Coastal Commission protects views of the coast from the water when reviewing proposed development projects (Douglas 2004). The Commission reviews proposals where views of boaters, fishermen, and other water users, as well as those of people on land looking across from other coastal viewpoints, may be affected. There have been some instances where proposals were rejected (or forced to be redesigned) largely based on their potential for interfering with water-based views. Local coastal plans are land-use plans designed to guide development and protect natural resources in communities and counties in California. To be certified by the California Coastal Commission, local coastal plans are required to contain provisions related to protecting scenic resources in the coastal zone. Local coastal plans have been adopted and approved for almost 90 percent of the coastal communities in the State (California Coastal Commission 2007).

The most common types of armoring or engineered hard structures include:

- **Seawalls and Bulkheads**: These structures are more common when erosion is taking place in front of costly infrastructure such as large hotels or high-value properties. These are often large concrete structures designed to withstand storm waves (Hayes and Michel 2010) (Figure 8). Historically, seawalls have been built to protect the properties behind them and not the beaches. Once constructed, seawalls can have three potential impacts: impoundment, passive erosion, and active erosion. Impoundment is the area lost because of the structure itself. Passive erosion results when there is landward shoreline migration subsequent to a hard structure being built. The result will be the gradual loss of the beach in front of the seawall as the water deepens and the shoreface migrates landward. Active erosion occurs downcoast of the seawall. The extent of scour downcoast of the seawall appears to be a function of the wall orientation, the angle of wave approach, and wave height and period (Griggs and Tait 1988; Griggs 2005). Bulkheads are typically made of wood or sheet-piling and are generally much smaller than seawall structures.
• **Revetments**: Revetments often use rocks in an engineered design to fortify the shoreline (Figure 9 and Figure 10). Stones are placed along a sloped or rough face and, if properly constructed, result in less bottom scour and wave reflection on the fronting beach or subtidal area. Revetments also can be constructed using other substrates such as concrete, concrete filled fabric bags, and gabion baskets. Often, revetments are placed on California beaches for temporary or emergency shoreline protection. These structures can vary in the quality of engineering. Rocks that have been dumped haphazardly are termed rip-rap. There are many examples, either unplanned or unpermitted, of emergency revetment structures and rip-rap along the California coast (Griggs et al. 2005).
Figure 9. A gabion is a steel wire mesh basket available commercially. 

Revetments can be constructed from stone-filled gabions. A step design is suggested to reduce wave runup. The structure should rest on an 18” thick gabion mattress to protect against scour. This type of construction is applicable to all shore-protection problems. Source: USACE

Figure 10. Stone revetment. 

Stones are placed carefully in an engineered design. Source: Directorate for Water Resources
Hard structures—controlling sand movement for beach protection

- **Breakwaters**: While breakwaters are normally constructed for protection of harbors, ports, and marinas, there are two breakwaters along the California shoreline built to reduce wave energy hitting the beaches. This causes sand to collect, often forming tombolos (Figure 11). These can interrupt longshore transport and subsequently cause erosion on the downdrift side of the breakwater (Hayes and Michel 2010).

![Figure 11. Offshore breakwater, Venice Beach, California. Source: Adelman and Adelman 2002–2010](image)

- **Groins**: Groins are common shore protection structures built perpendicular to the shoreline to trap sediment on an updrift beach (Figure 12). They sometimes are made of rubble, but other materials, such as wood, rocks, sand bags, or gabions, are also used (Hayes and Michel 2010). Groins are best utilized if there is a significant amount of sediment in the system and the transport is unidirectional or has been artificially nourished. Multiple groins are usually installed to increase beach sedimentation along a stretch of shoreline with a terminal groin being the most downcoast structure in the groin field. Groins also can lead to erosion of the shoreline. As they increase sand on the updrift side of the groin, they starve the beach on the downdrift side as well as the coast beyond the last groin. Wave diffraction at the tip of the groin can cause waves to break parallel to the coast, exacerbating erosion along the shore (Hardaway and Byrne 1999). Small groins are typically composed of large rock or wood. Permeable groins maintain some natural sediment transport by allowing a limited amount of sediment to pass through the structure. Permeability is created by shortening or notching the groin, increasing material porosity, and reducing offshore crest elevations (Rankin et al. 2003).

The downdrift erosion can be minimized by what is termed sand by-passing (i.e., pumping sand from the updrift side to the downdrift side, or by sand nourishment of the downdrift beach, and/or prefilling of the groins).
Soft Structures (i.e., actions)

The most common form of soft coastal engineering in California is beach nourishment, which is the artificial placement of suitable sediment in a sediment-deficient coastal environment. Sediment can be obtained from an off-shore dedicated source by dredging operations, or from navigation-dredged projects that are deepening navigation channels (i.e., beneficial use of dredged material).

The types of soft structures/actions for shoreline management include:

- Initial beach nourishment;
- Re-nourishment;
- Sand by-passing;
- Environmental (ecosystem) restoration;
- Redirecting tidal inlet characteristics; and
- Placement of dredged material from navigation projects in the littoral zone or directly on the beach.

**Beach nourishment:** Beach nourishment is used for erosion control, providing wider beaches to reduce coastal flood and wave damage, increasing recreation, enhancing habitats for threatened and endangered species, or integrating with navigation projects such that a source of sediment (e.g., navigation dredging) is matched with a beach. These approaches are often preferred over hard structures because the fill adds sand to a deficient coastal sediment budget, provides a wide berm for storm protection and recreation, is aesthetically pleasing, and does not create structural impediments to beach access. Common disadvantages are their high cost, short lifespan of 3–5 years compared to some hard structures (with design lifespans of up to 50 years), and need for periodic re-nourishments. Stakeholders need to be involved because beach nourishment projects are not without environmental concerns (e.g., do the grain sizes match or does the new sediment create a foul odor?).
Environmental restoration or enhancement: Restoration or enhancement of wetlands and salt marshes provides a multitude of ecosystem benefits, including habitat for fish and wildlife and flood control. These projects generally add compatible sediments to maintain sufficient elevations in the marshes, along with other project elements such as planting of wetland plants.

Sand by-passing: Sand by-passing is a frequent response to accretion of sand updrift of navigation projects, including jetties. The response of adjacent shorelines to channel construction and maintenance depends upon the navigation project design, presence of jetties, and the mitigation used to minimize project impacts. Where a jetty is present, substantial quantities of sand can be trapped along the side of the jetty, as the longshore drift of sand is interrupted by the jetty. Adjacent shorelines are deprived of the sand accumulated, and the implied erosion rate of the downdrift shoreline is the same as the impoundment rate at the updrift jetty and within the ebb and flood shoals. The management practice is to by-pass sand, that is, sand is pumped to the downdrift side from the updrift side of the structure, where sand has accumulated.

Redirecting tidal inlet characteristics: Inlet influenced erosion can be reduced by proper design and maintenance. Evaluation of dredging and shoreline erosion history is useful in determining the inlet configuration and channel alignment that will result in the least maintenance. As reported by Price (1952), it may be possible to reduce accretion and erosion by realigning navigation channels such that they are more akin to, instead of in opposition to, the dominant natural forces.

Dredging: Dredging is the primary response to shoaling (sediment accretion) of California’s harbors and ports. As can be seen in the Crescent City case study in Section 7, shoaling can impede ship and boat access and affect local ocean economies. Between 1996 and 2005, USACE dredged, on average, 4.3 million cubic yards of sand per year from 25 navigation projects along the California shoreline, two-thirds of which occurred in the southern part of the State (Conner et al. 2006). Coupling dredging operations (for bypass or navigational projects) with beach nourishment (beneficial use) is generally viewed as a cost-effective strategy to simultaneously address accretion and erosion (Box 4).

Over the last decade, the importance of sediments in the littoral zone has been increasingly recognized by USACE and other federal and state agencies. Historically and continuing today in many situations, the USACE Federal Standard has resulted in disposal of dredged material in deep offshore waters, lost to the littoral zone. The Federal Standard states that federal navigation dredging projects are required to select the least-cost, environmentally acceptable disposal alternative for dredged material. The USACE is a champion of beneficial use of dredged material including beach nourishment, but the requirement for the least-cost alternative mean that local sponsors of beach nourishment or wetland enhancement projects must provide the increased costs over the base plan (i.e., federal standard). Since the early 2000s, the concept of systems approaches to sediment management has influenced acceptable disposal alternatives for dredged material which now include placement into the littoral zone; appropriate conditions have to be met, such as grain size, chemical and toxicological quality of the dredged material, depth of closure, and an acceptable receiving environment, such as longshore currents.
Examples of innovative ways dredged material is being used in the State are shown in several case studies in Section 7 of this report. See case studies on Crissy Field: placing dredged material in the littoral zone, San Francisco Bay: Long Term Management Strategy, Port of Long Beach: disposal site for contaminated dredged material from numerous dredging projects, and Hamilton Airfield: wetland restoration.

**Non-structural shoreline management**

Non-structural shoreline management practices include policies, regulations, and other methods to control human activities that affect the coastal zone. These solutions can include relocation of development along the shoreline, retreat from the coast, elevation of structures, and the implementation of zoning restrictions and setback lines. The use of setback lines is more effective for areas that are not yet developed. Shoreline retreat is often not considered a realistic approach because of the inevitable loss of infrastructure, high property tax revenues, and effects to tourism. The current policies and regulations are evolving, and will continue to evolve as sea level rise and climate change issues will be addressed. The California Coastal Sediment Management Workgroup (see section 6) is actively reviewing sediment management policies and regulations.

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**Box 4. Beneficial Use of Dredged Material**

Using dredged material for beach nourishment and wetland restoration can be a cost-effective strategy in many cases, given the continual sediment accretion in many ports and harbors and sediment deficits in other areas.

- Annual dredging in the State is about 4.3 million cubic yards.
- A major challenge is the location of the dredging and the distance to the beaches or littoral zone where sediment is needed. Hauling dredged material appreciable distances is very expensive.

The solution is to match, as much as possible, navigation dredging projects with locations that need sediment, and seek sponsors for funding.
Sediment Budgets—First Step to Managing Erosion and Accretion

Concept of Sediment Budgets

Sediment flow in coastal areas is a complex process that affects the physical environment, marine life, and human communities along the coast. Coastal sediment refers to organic and inorganic particles created through erosion, fluvial drainage, human activities, and other processes (Hapke et al. 2006). Modes of sediment transport include wind, river or stream transport from upland areas to the coast, or processes occurring in the marine environment such as longshore transport. Coastal sediment is in a constant state of flux because of natural forces from wind and waves—these forces continually erode and sometimes accrete coastal land features, such as beaches, dunes, inlets, bluffs, and coastal marshes.

To quantify the amount of sediment lost or added to beaches, scientists use the concept of sediment budgets (Figure 13). A sediment budget computes the various inputs and outputs of sediment to determine the net quantity of sand along a shoreline. Areas where sand is added to the beach are called “sources” and where it is lost offshore or onshore (e.g., dunes) are called “sinks.” The California coast can be broken into geographically distinct compartments that consist of sources and sinks of sand. Those are called littoral cells (Figure 14).

Littoral cells are more or less self-contained beach compartments that are geographically limited. Figure 14 demonstrates how littoral drift and longshore transport move sand along and perpendicular to the shoreline within a littoral cell. The most common natural sediment sources are rivers, streams, and sandy coastal bluffs. Sediment sinks include coastal dunes and submarine canyons (Patsch and Griggs 2006). Navigation channels created by dredging also create sediment sinks (as can jetties, groins, and breakwaters), but those sediments are not necessarily lost to the system if maintenance dredging results in placing the material on beaches or in the littoral zone along the shoreline.

![Figure 13. Depiction of a littoral cell and the concept of a sediment budget with the various sources and sinks for sediment. Source: Komar 1996](image-url)
Sediment Budgets in California

The California shoreline has been divided into 25 major littoral cells or beach compartments (Figure 14). Patsch and Griggs (2006, 2007, 2008) have developed detailed sand budgets for those littoral cells. In California, sediment budgets have been developed for many of its littoral cells by making calculations and estimates of the amount of sand added by various sediment sources and removed by sediment sinks, by evaluating the volume of sand moving by littoral drift, and through examination of harbor dredging records (Patsch and Griggs 2006). Table 1 provides a summary of the primary sources/sinks for California’s coastal sediment budgets.

Figure 14. Map of California showing the 25 major littoral cells along the coast and the approximate direction of littoral transport.

Source: California Department of Navigation and Ocean Development 1977; See more recent Patsch and Griggs 2006
Human activities such as dam construction, debris basins, coastal armoring, sand mining, or restriction of littoral transport from engineered structures along the coast will contribute to the erosion of beaches because of a diminished or absent sand supply.

**Table 1. Summary of major sediment sources and sinks for littoral cells.**
*Source: Hayes and Michel 2010; Patsch and Griggs 2006*

<table>
<thead>
<tr>
<th>Type</th>
<th>Sediment Sources</th>
<th>Sediment Sinks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural</td>
<td>River inputs</td>
<td>Loss to submarine canyans</td>
</tr>
<tr>
<td></td>
<td>Aeolian transport and dune erosion (not common)</td>
<td>Aeolian transport and dune growth</td>
</tr>
<tr>
<td></td>
<td>Longshore transport and cross-shore exchange of sediment between nearshore and offshore</td>
<td>Longshore transport and cross-shore exchange of sediment between nearshore and offshore</td>
</tr>
<tr>
<td></td>
<td>Sea cliff/Bluff erosion</td>
<td>Tidal inlet processes</td>
</tr>
<tr>
<td>Human-induced</td>
<td>Dredged material disposal</td>
<td>Sand mining</td>
</tr>
<tr>
<td></td>
<td>Beach nourishment and artificially placed material</td>
<td>Dams on rivers</td>
</tr>
<tr>
<td></td>
<td>Navigation channels and berths, depending on disposal alternatives selected</td>
<td>Navigation channels and berths</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hard structures such as seawalls, revetments, jetties, and groins (i.e., prevent sand from eroding from bluffs)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Diversion of rivers</td>
</tr>
</tbody>
</table>

California beach sediment ranges from very-fine-grained sand to cobbles. Sediment size depends on the wave energy and available materials. Energetic coasts, which are common in California, tend to have no silt-to-clay-sized sediment because these remain in suspension within the water column and settle out of suspension offshore or can be deposited within the calmer waters of estuaries, lagoons, and bays.

A study by Hicks (1985) observed that there is a littoral cut-off diameter for particular sections of the coast that provides a limit to what sized grains will remain on the dry beach. The size of a littoral cut-off diameter depends on wave energy. The littoral cut-off diameter is important to take into account in planning beach nourishment projects or calculating littoral budgets because sand brought into a littoral cell that is finer than the littoral cut-off diameter will not stay on the beach. Sand and smaller-sized gravel particles will travel alongshore in appreciable quantities and also will be exchanged within the beach, surf zone, and inner nearshore water. Additional information can be found in Limber et al. (2007) and Runyan and Griggs (2003).

The movement of sand within a given littoral cell is greatly influenced by seasonal changes in wave energy. In the winter, the beach berm will narrow and sand will build up offshore bars, which are linear mounds of sand that form parallel to the beach. In the summer, waves will move sand back up onto the beach from the bars. In addition to seasonal changes, the beach may undergo a significant change in a matter of days or hours depending on notable changes in the wave climate.
Griggs et al. (2005) estimated the amount of sand that travels along the shoreline at several locations based on the long-term dredging volumes (Table 2).

**Table 2. Estimated annual littoral drift rates and directions along the California Shoreline.**  
*Source: Griggs et al. 2005*

<table>
<thead>
<tr>
<th>Location</th>
<th>Annual Rate (Cubic Yards)</th>
<th>Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Santa Cruz</td>
<td>300,000</td>
<td>East (Downcoast)</td>
</tr>
<tr>
<td>Santa Barbara</td>
<td>300,000</td>
<td>East (Downcoast)</td>
</tr>
<tr>
<td>Ventura</td>
<td>600,000 – 1,000,000</td>
<td>Southeast (Downcoast)</td>
</tr>
<tr>
<td>Santa Monica</td>
<td>275,000</td>
<td>Southeast (Downcoast)</td>
</tr>
<tr>
<td>Oceanside</td>
<td>350,000</td>
<td>South (Downcoast)</td>
</tr>
</tbody>
</table>

Most natural beach sand is supplied from rivers that extend to the ocean with a smaller percentage from erosion of sea cliffs and bluffs. Important sand suppliers are the Eel, Russian, Santa Maria, Ventura, and Santa Clara Rivers. Southern California differs from this description because most coastal rivers have dams that impound their sediment supply. Therefore, to a greater degree than in Northern California, small streams and coastal bluffs provide a greater proportion of sediment in that region.

Historically, California’s coastal rivers naturally supplied sediment such as gravel, sand, silt, and clay to the coast. According to a study by the California Department of Boating and Waterways (2002), there are more than 1,400 dams over 25 feet high or impounding more than 50 acre-feet of water in California with 539 of these dams located in coastal watersheds that drain directly into the Pacific Ocean. Sediment supply has been reduced by 50 percent to half of Southern California’s littoral cells (Table 3). Overall impediments to the supply side are shown in Box 5.

**Table 3. Reductions in sand supply by dams in major California rivers.**  
*Source: Griggs et al. 2005; Slagel and Griggs 2008; and Willis and Griggs 2003*

<table>
<thead>
<tr>
<th>River</th>
<th>Percent Reduction in Sand Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>Santa Maria River</td>
<td>68%</td>
</tr>
<tr>
<td>Ventura River</td>
<td>53%</td>
</tr>
<tr>
<td>Los Angeles, San Gabriel, Santa Ana Rivers</td>
<td>67%</td>
</tr>
<tr>
<td>San Dieguito River</td>
<td>79%</td>
</tr>
</tbody>
</table>
Patsch and Griggs (2007) present Individual sand budgets for the major littoral cells. Their detailed analyses show the relative importance of sand sources for each littoral cell. Under present and dammed conditions (excluding beach nourishment):

- Fluvial inputs constitute about 87 percent of the sand entering California’s major littoral cells, and contribute 90 percent of the sand to Southern California (from the start of the Santa Barbara littoral cell to the international border).
- On a statewide basis, contributions to beach sand from sea cliff erosion tend to be much less than those from streams. However, such contributions may be locally important where sandy cliffs are rapidly eroding and there are no large streams (Runyan and Griggs 2003).
  - For example, while bluff erosion contributes less than one percent of the sand to the Santa Barbara littoral cell, bluff erosion is believed to contribute about 31 percent and 60 percent of the sand to the Laguna and Mission Bay littoral cells, respectively.
  - Recent research in the Oceanside littoral cell, using the composition of sand in the bluffs and beaches, as well as precise LiDAR measurements of coastal bluff retreat (over a relatively short 6-year period) concluded that bluffs are a significant sediment source of beach sand contributing 67 percent or more of the sand to beaches in this littoral cell. Gullies and rivers contributed 17 percent and 16 percent, respectively (Young and Ashford 2006).
  - Statewide, dune deflation or erosion accounts for 8 percent of the littoral sand (excluding beach nourishment).
in California’s major littoral cells, beach nourishment is taken as a contributing source of sand; the relative importance of rivers, bluffs, and dunes statewide drops to 72 percent, 4 percent, and 7 percent, respectively. Beach nourishment accounts for the remaining 17 percent of the sand.

- Beach nourishment has added 1,300,000 cubic yards per year on average to the overall sand budget for California’s major littoral cells, all of this along the Southern California shoreline.
- In Southern California, beach nourishment represents 31 percent of the sand supplied to the beaches. This figure is critical to understand projected coastal change in light of the fact that fewer beach nourishment projects are occurring today.

However, beach nourishment has not completely supplemented or replaced the volume of sand prevented from reaching the beaches through damming and armor ing sea cliffs. The majority of beach nourishment projects took place during the 1950s to 1970s as a result of large coastal construction projects. The decline in beach nourishment since that time represents an overall reduction of sediment supply that is greater than that reduced from dams and armor ing. The decline in beach nourishment projects also coincided with the shift in climate regimes from a dry, calm La Niña to the wetter El Niño conditions, which increased the fluvial supply of sediment by 20 times. This shift in climate to El Niño resulted in an increase in natural sand supplied to the beaches and made up for the reduction in beach nourishment that happened at the same time (Grandy and Griggs 2009) (Box 6).

Anthropogenic reductions to the sand supply in these littoral cells stem from the damming of rivers, armor ing of sea cliffs, and mining of beach sand. Overall:

- Damming of rivers has resulted in the reduction of about 25 percent of the natural sand supplied to the coast, a volume over 2,500,000 cubic yards per year.
- The armor ing of sea cliffs has reduced the sand supply to these littoral cells from cliff and bluff erosion by 11 percent or about 43,000 cubic yards per year.
- Several companies mined sand from the beaches of southern Monterey Bay until approximately 1985 at a rate of about 180,000 cubic yards per year. Since then, a single sand plant has been removing approximately 180,000 cubic yards per year. Magoon and Lent (2005) summarized what is known about sand and gravel mining in California streams, which represents a potential long-term loss of sand to the shoreline. In addition, they determined that a total of about 50 million cubic yards of sand and gravel are removed annually through streambed mining. However, it is unclear how much of this material would naturally be delivered to the coast.

**Box 6. Hungry Water and Hungry Waves**

"From our work on the long-term beach width changes in Southern California (Orme, et al.), it seems clear that despite what should be declines in sand input (from dam construction, for example), and therefore “deficits”, the beaches are not systematically getting narrower. There are cells where width seems to oscillate with PDO cycles, cells where beaches rotate, and cells where the beaches have always been narrow. I believe the system is capable of making up deficits, more sand picked up from streambed downstream from dams (“hungry water”), picking up sand from nearshore zone (“hungry waves”)." (Griggs 2013)

In summary, the development of a sediment budget is extremely important for shoreline managers who want to institute proper sediment management practices. A sediment budget identifies transport fluxes and
pathways to quantify what is observed. However, coastal managers are cautioned that sediment budgets and characteristics of littoral cells are scientifically challenging, and the uncertainties in the existing sediment budgets for the California shoreline should be understood by coastal managers. Uncertainties relate to the incomplete understanding of sediment movement, the challenges of collecting precise data and information given the practical limits of instrumentation, and variations in the direction and quantity of sediment movement. Thus, shoreline managers and policy makers should have a good understanding of the sediment processes and shoreline conditions within their geographic area of interest.

Erosion of the California Shoreline

Shoreline Response to Erosion and Accretion, including Implications of Sea Level Rise

The forces of erosion and accretion have significant effects on dunes, beaches, cliffs, and bluffs; loss of marshes/wetlands; increasing salinity in estuaries; and changing habitats for animal and plant life.

Cliffs and Bluffs

Cliffs and bluffs erode primarily from the physical forces of wave energy, but other factors include rainfall, runoff, and ground water seepage. The amount of wave energy expended on the coast is determined by the effects of wave height, tidal elevation or sea level, offshore and beach profile and slope, and beach width and height. Combined, these factors may significantly influence wave run-up and thus exert a major control on the forces applied to the cliff, bluff, dune, or beach face (Benumof and Griggs 1999). Figure 15 shows erosion of cliffs supporting Highway 1 which is subject to intermittent slope failures. The section is slated to be bypassed.

Usually being episodic events, cliffs and bluffs retreat via large blocks failing and sliding onto the beach or into the coastal waters. With large landslides, the shoreline may actually be extended for a decade or more before wave action removes the material off the beach, at which point the cliffs or bluffs will be noted as eroding. Thus, measurement of erosion rates for cliffs and bluffs needs to be conducted over longer term frames (i.e., many decades).

Figure 15. Devil’s Slide portion of Highway 1.
Adelman and Adelman 2002–2010
The primary response to protection of cliffs and bluffs has been the construction of seawalls and revetments; over 10 percent of the shoreline is now armored, with 33 percent of the coastline armored in the four most developed counties in Southern California: Orange, Los Angeles, Ventura, and San Diego (NRC 2012). Shown in Figure 16, erosion of poorly consolidated sedimentary cliffs at Pacifica, south of San Francisco, threatened apartments, and residents had to relocate. Riprap protection was placed at the toe of the bluff in an attempt to slow the erosion.

*Figure 16. Cliff erosion threatening residential real estate. Source: Hawkeye Photography. NRC 2012.*

**Beaches**

Beaches are particularly susceptible to erosion from sea level rise, given that a small increase in the sea level can inundate the full width of the beach. The long-term effects of declining sand supply in concert with increases in sea level (see Section 3) works to progressively narrow beaches, unless those beaches can migrate or retreat inland. The supply of sand has been reduced by 25 percent as a result of the 500 water supply and flood control dams upstream of California’s shoreline (Willis and Griggs 2003). In Southern California, 150 debris basins in the watersheds of eight major rivers have impounded more than 4 million cubic meters of sand. Statewide, 152 million cubic meters has been trapped by coastal dams (NRC 2012).

Installed at many beaches is some sort of armoring to lessen the erosion of the cliffs or bluffs that cannot naturally migrate inland (e.g., commercial development on top of the cliff). The challenge with this response is that the seawalls and revetments were designed for a certain set of sea level and wave conditions. Over time, these armored shorelines will likely be inundated and lose their protective services (NRC 2012). Eventually most, if not all of California armored beaches will be inundated depending on the rate of sea level rise.

**Coastal Dunes**

Coastal dunes are vulnerable to rapid erosion from storms and these effects will be exacerbated by rising sea levels. Dunes accrete or expand, provided they have an ample supply of sand and onshore winds.
California’s dunes are still active and forming, but they have a lower supply of sediment. A number of housing developments have been constructed on dunes along the shoreline, and some are threatened by erosion, given the decreased availability of sand.

**Estuaries and Tidal Marshes/Mudflats**

Estuaries, tidal marshes, wetlands, and mudflats provide a variety of ecosystem services, including fisheries and recreational and commercial fishing, habitat for fish and wildlife, overwintering habitat for migratory waterfowl, reduction in nutrient loading to the coastal ocean, and protection from flooding by damping storm surges from the ocean. The primary physical factors associated with survival of tidal marshes and wetlands in relation to sea level rise are the availability of sediment, tidal conditions, and the coastal configuration. The response of mudflats and marshes to sea level rise depends on the balance between submergence, erosion, and sediment supply. If compaction rates exceed accretion rates, the dominant plant species may die off, eliminating their ability to trap sediments and the ecosystem services provided by that particular marsh.

Estuaries include subtidal areas, intertidal flats, and vegetated marshes. Changes in sea level may change the tidal dynamics within the estuary, including the tidal range with attendant impacts, such as saltwater penetration, duration of flooding or exposure to intertidal flats and marshes, the depth of flooding and wave action, and the potential for erosion. The spread of emergent vegetation provides an effective trap for suspended sediments, which in turn stabilizes intertidal flats. The transition from intertidal flats to marshes is especially sensitive to changes in sea level.

An estimated 670 square miles, or 430,000 acres, of wetlands exist along the California coast. Sea level rise will likely cause landward migration of these wetlands/marshes and mudflats, but this depends on the coastal configuration, site-specific conditions, and an unobstructed pathway for migration. New marshes may be created inland, but the dominance of cliffs, bluffs, and development along the coastline limits the extent of inland migration for many of the existing marshes, mudflats, and wetlands. Whether marshes, wetlands, and mudflats can survive or migrate in response to sea level rise depends on their location and their ability to build elevation, which in turn depends on a supply of sediment. Herberger estimated that a sea level rise of 1.4 meters would flood approximately 150 square miles of land immediately adjacent to current wetlands, potentially creating new wetland habitat if those lands are protected from further development (Herberger et al 2009).

The National Research Council (NRC) concluded that predicting the survival of salt marshes is complex, because it depends on a source of organic sediments for marsh vertical development, the role of storms, soil conditions, and plant growth. Other research has indicated that temperature and increased levels of CO$_2$ in the atmosphere also can affect plant growth in a positive manner.

The NRC noted that one study in the San Francisco Bay Area showed that marshes are sustainable even for a predicted 1.4-meter sea level rise as long as there are sufficiently high rates of suspended sediment supply. Another study concluded that marshes in San Francisco Bay can keep pace with sea level rise of 6 mm per year, which is projected for 2030 and 2050 (Parker et al. 2011). The sediment supply in San Francisco Bay is carried from rivers, but that supply has decreased over time from the construction of upstream reservoirs.
On the Northern California coast, mudflats and tidal marshes are mostly isolated areas around the major estuaries, such as Humboldt Bay, which tend to be narrow without extensive mudflats for storing sediments. These marshes and mudflats depend on the fluvial delivery of sediment. The NRC concluded that, for 2030 and 2050, survival of marshes is more dependent on riverine sediment delivery, local development pressures, and changes in tidal hydrology than sea level rise; in the event that the highest levels estimated for sea level rise occur, only the marshes in areas of high optimal sediment supply would survive.

**Rates of erosion**

Observation and analysis of maps (historical and digitized), photographs, and LiDAR topographic surveys have been used to determine if an area is eroding or not.

- According to the 2006 U. S. Geological Survey (USGS) National Assessment of Shoreline Change, the overall long-term change for sandy shorelines on the California coast was accretional with an average of 0.2±0.1 m/yr (Hapke et al. 2006). Still, 40 percent of the measured transects had erosional trends. Southern California showed low erosion rates because of the protective effects of engineered coastal structures or beach nourishment projects (Hapke et al. 2006). Long-term rates were determined based on information from the 1800s, 1920s–1930s, 1950s–1970s, and LiDAR shoreline measurements from 1998–2002.

- The net short-term rate was erosional with an average rate of -0.2±0.4 m/yr, with 66 percent of transects eroding. Short-term rates are based on data from the 1950s–1970s and LiDAR shoreline measurements from 1998–2002. This short-term period may demonstrate a recent decrease in nourishment projects (Flick 1993; Wiegel 1994). The highest rates of accretion were found in Northern California, and highest erosion in Southern California. Central California generally had lower rates of both accretion and erosion (Hapke et al. 2006).

- For comparison, the continental shelf width along the California coast averages 15–30 km from the shoreline, from 5 km or less off of Big Sur to 40 km off of San Francisco. This is a reflection of the fact that the shoreline has been retreating since the last ice age ended about 21,000 years ago, at which time the western shoreline of the California land mass was located at the edge of the continental shelf. The NRC (2012) calculated that the average retreat rate varied from 0.024 meters per year to 0.19 meters per year, based on the extent of the existing continental shelf of 5 km to 40 km.

The rates of cliff retreat along the California shoreline range from a few centimeters per year for granitic or volcanic rock to tens of centimeters per year for unconsolidated materials or sedimentary rocks. Specific estimates by researchers include:


- Griggs et al. (2004) found that cliffs and bluffs made of sedimentary rocks typically erode at rates of 15 to 30 cm per year.

The 2007 USGS National Assessment of Shoreline Change reported the results of an assessment of the rate of coastal cliff retreat along the California shoreline (Hapke and Reid 2007). The average rate of
coastal cliff erosion for the shoreline was -0.3±0.2 meters per year. This was based on averaging cliff erosion rates from 17,653 individual transects. The average amount of cliff erosion over the 70-year time period was 17.7 meters. Retreat rates were found to be generally lower in Southern California cliffs than in Northern California. The USGS stated that one of the reasons was because of more armoring of the shoreline where the population pressures and needs for protection of infrastructure and real estate are higher. The USGS results are shown in Table 4 and Table 5.

- Table 4 provides the average retreat rates within each region of the shoreline.
- Table 5 provides maximum retreat rates for specific areas within the regions. These tables are reproduced from the 2007 USGS report (Hapke and Reid 2007). Estimation of the rates of erosion are not without issue, as many variables exist along each section of shoreline that can have significant effects on local rates of erosion. These spatial variables are demonstrated in the reference guide, *Living with the Changing California Coastline* (Griggs et al. 2005) included in which are mile-by-mile maps including geomorphology of the entire coastline.

### Table 4. Average cliff retreat rates for California shoreline

*Source: Hapke and Reid 2007*

<table>
<thead>
<tr>
<th>Region</th>
<th>Number of Transects</th>
<th>Length of Region (km)</th>
<th>Length of Measured Cliffs (km)</th>
<th>Average Retreat Rate (m/yr ± 0.2)</th>
<th>Average Retreat amount for 70 years (m) ±10.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Klamath</td>
<td>319</td>
<td>101</td>
<td>6</td>
<td>-0.5</td>
<td>-36.2</td>
</tr>
<tr>
<td>Eureka</td>
<td>135</td>
<td>154</td>
<td>3</td>
<td>-0.7</td>
<td>-53.4</td>
</tr>
<tr>
<td>Navarro</td>
<td>1,441</td>
<td>142</td>
<td>29</td>
<td>-0.4</td>
<td>-28.9</td>
</tr>
<tr>
<td>Russian River</td>
<td>433</td>
<td>102</td>
<td>9</td>
<td>-0.2</td>
<td>-15.3</td>
</tr>
<tr>
<td><strong>Northern CA</strong></td>
<td><strong>2,325</strong></td>
<td><strong>499</strong></td>
<td><strong>47</strong></td>
<td><strong>-0.5</strong></td>
<td><strong>-28.8</strong></td>
</tr>
<tr>
<td>San Francisco North</td>
<td>1,092</td>
<td>119</td>
<td>22</td>
<td>-0.5</td>
<td>-36.2</td>
</tr>
<tr>
<td>San Francisco South</td>
<td>1,551</td>
<td>99</td>
<td>31</td>
<td>-0.2</td>
<td>-16.4</td>
</tr>
<tr>
<td>Monterey Bay</td>
<td>1,098</td>
<td>76</td>
<td>22</td>
<td>-0.4</td>
<td>-24.4</td>
</tr>
<tr>
<td>Big Sur</td>
<td>1,929</td>
<td>145</td>
<td>39</td>
<td>-0.3</td>
<td>-17.2</td>
</tr>
<tr>
<td>Morro Bay</td>
<td>738</td>
<td>91</td>
<td>15</td>
<td>-0.2</td>
<td>-12.6</td>
</tr>
<tr>
<td>Santa Barbara North</td>
<td>3,982</td>
<td>174</td>
<td>80</td>
<td>-0.2</td>
<td>-11.3</td>
</tr>
<tr>
<td><strong>Central CA</strong></td>
<td><strong>10,390</strong></td>
<td><strong>704</strong></td>
<td><strong>208</strong></td>
<td><strong>-0.3</strong></td>
<td><strong>-17.3</strong></td>
</tr>
<tr>
<td>Santa Barbara South</td>
<td>828</td>
<td>111</td>
<td>17</td>
<td>-0.2</td>
<td>-13.3</td>
</tr>
<tr>
<td>Santa Monica</td>
<td>1,118</td>
<td>91</td>
<td>22</td>
<td>-0.3</td>
<td>-17.9</td>
</tr>
<tr>
<td>San Pedro</td>
<td>498</td>
<td>87</td>
<td>10</td>
<td>-0.2</td>
<td>-9.8</td>
</tr>
<tr>
<td>Oceanside</td>
<td>1,993</td>
<td>86</td>
<td>40</td>
<td>-0.2</td>
<td>-12.0</td>
</tr>
<tr>
<td>San Diego</td>
<td>501</td>
<td>48</td>
<td>10</td>
<td>-0.2</td>
<td>-12.0</td>
</tr>
<tr>
<td><strong>Southern CA</strong></td>
<td><strong>4,938</strong></td>
<td><strong>400</strong></td>
<td><strong>99</strong></td>
<td><strong>-0.2</strong></td>
<td><strong>-13.3</strong></td>
</tr>
<tr>
<td><strong>State Totals</strong></td>
<td><strong>17,653</strong></td>
<td><strong>1,603</strong></td>
<td><strong>353</strong></td>
<td><strong>-0.3</strong></td>
<td><strong>-17.7</strong></td>
</tr>
</tbody>
</table>
Table 5. Maximum Cliff Retreat Rates
Hapke and Reid 2007

<table>
<thead>
<tr>
<th>Region</th>
<th>Max. Retreat Rate (m/yr) ±0.2</th>
<th>Max. Retreat Amount for 70 years (m) ±10.9</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Klamath</td>
<td>-2.3</td>
<td>-167.9</td>
<td>2.6 km north of the Klamath River mouth</td>
</tr>
<tr>
<td>Eureka</td>
<td>-2.2</td>
<td>-161.3</td>
<td>False Cape, 7.3 km north of Cape Mendocino</td>
</tr>
<tr>
<td>Navarro</td>
<td>-3.1</td>
<td>-222.7</td>
<td>Rockport Beach, near Cape Vizcaino</td>
</tr>
<tr>
<td>Russian River</td>
<td>-0.8</td>
<td>-60.5</td>
<td>Bodega Head</td>
</tr>
<tr>
<td>San Francisco North</td>
<td>-1.9</td>
<td>-138.7</td>
<td>Point Reyes</td>
</tr>
<tr>
<td>San Francisco South</td>
<td>-3.1</td>
<td>-210.5</td>
<td>2.3 km north of the Pillar Point Harbor breakwater</td>
</tr>
<tr>
<td>Monterey Bay</td>
<td>-1.8</td>
<td>-116.4</td>
<td>Sand City Beach</td>
</tr>
<tr>
<td>Big Sur</td>
<td>-2.2</td>
<td>-147.6</td>
<td>Pfeiffer Beach</td>
</tr>
<tr>
<td>Morro Bay</td>
<td>-0.8</td>
<td>-52.5</td>
<td>3 km north of Cayucos beach</td>
</tr>
<tr>
<td>Santa Barbara North</td>
<td>-1.3</td>
<td>-81.3</td>
<td>Point Sal</td>
</tr>
<tr>
<td>Santa Barbara South</td>
<td>-1.0</td>
<td>-63.1</td>
<td>Arroyo Burro (Hendry’s) Beach</td>
</tr>
<tr>
<td>Santa Monica</td>
<td>-1.8</td>
<td>-115.1</td>
<td>Big Rock Beach, Bick Rock Mesa landslide</td>
</tr>
<tr>
<td>San Pedro</td>
<td>-1.0</td>
<td>-64.0</td>
<td>Point Fermin, Sunken City landslide</td>
</tr>
<tr>
<td>Oceanside</td>
<td>-1.7</td>
<td>-110.1</td>
<td>San Onofre Beach South</td>
</tr>
<tr>
<td>San Diego</td>
<td>-1.6</td>
<td>-99.8</td>
<td>Sunset Cliffs, Point Loma</td>
</tr>
</tbody>
</table>

Erosion rates and coastal retreat vary widely in time and space. Granite cliffs and bluffs are generally resistant to erosion, whereas the relative weakness of poorly-consolidated sediments results in higher erosion rates. Thus, significantly different erosion rates are found along the shoreline, from negligible to 10 feet per year. In general, coastal cliffs are eroding an average of about one foot per year. The sedimentary rocks that form much of California’s shoreline have retreated at long-term average rates of a few inches to more than one foot per year (Griggs et al. 2005).

Erosion also tends to be an episodic process. Much of the erosion occurs from major storms every five to ten years, when large sections of cliffs or bluffs collapse, followed by relatively stable periods (Griggs et al. 2005).

Average erosion rates have been determined for specific areas in Southern California. Comprehensive assessments have been conducted for many areas of the entire shoreline. A study sponsored by the Federal Emergency Management Agency (Heinz Center 2000; Moore et al. 1999) documented long-term erosion rates for Santa Cruz and San Diego Counties.
Griggs et al. (2005) provides erosion rates from available data for the entire State. In this book, 12 regional chapters, covering the California shoreline from Oregon to Mexico, Griggs describes the geology, hazards, and histories of individual areas. Every mile of the shoreline is depicted in a series of maps that delineate the type and extent of coastal development, locations of armored shorelines, and information on coastal erosion rates.

The California Coastal Commission conducted an inventory, still unpublished, of all erosion rates for the entire State from their permit data base.

**The California Coastal Erosion Survey**

The California Coastal Sediment Management Workgroup sponsored an assessment of the shoreline to identify areas where historical or current erosion is of concern to federal, state, or local entities. The basis for the survey was one of the fundamental principles of sediment management: to identify problem areas, such as eroding beaches across regional areas, while looking for solutions beyond the immediate problem area. The survey resulted in a list of Beach Erosion Concern Areas (CSMW 2010).

The California Department of Boating Waterways, which conducted the survey, asked local communities and public agencies across coastal California to respond to a questionnaire about the magnitude and extent of shoreline erosion in their area. Local and regional entities contributed their concerns on which beaches should be listed. The USACE listed beaches with erosion issues with federal interest. The list was refined through field investigations, and beaches were eliminated from the list if the erosion was caused by non-marine related influences, such as hydrological processes, stormwater runoff, ground water seepage, or unstable soil conditions.

After the initial construction of the list of beaches, conceptual solutions to the erosion problems were identified. Beaches for which the recommended response was construction of a hard structure, such as a seawall, were eliminated.

The list of Beach Erosion Concern Areas (Table 6) is considered a living list because beaches can be added or taken off the list as new information becomes available. The *California Beach Erosion Assessment Survey* includes map locations and brief discussions of erosion issues at each of the Beach Erosion Concern Areas (CSMW 2010). Simple descriptions of the erosion problems at a few of the beach erosion concern areas are included in Box 7 for illustrative purposes.
Table 6. Location Areas of Beach Erosion Concerns

<table>
<thead>
<tr>
<th>County</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alameda</td>
<td>Robert W. Crown Memorial State Beach</td>
</tr>
<tr>
<td>San Mateo</td>
<td>Coyote Point</td>
</tr>
<tr>
<td>San Francisco</td>
<td>Ocean Beach (San Francisco)</td>
</tr>
<tr>
<td>San Mateo</td>
<td>Princeton</td>
</tr>
<tr>
<td>San Mateo</td>
<td>El Granada County Beach</td>
</tr>
<tr>
<td>Monterey</td>
<td>Southern Monterey beaches</td>
</tr>
<tr>
<td>Santa Barbara</td>
<td>Refugio State Beach</td>
</tr>
<tr>
<td>Santa Barbara</td>
<td>El Capitan State Beach</td>
</tr>
<tr>
<td>Santa Barbara</td>
<td>Isla Vista</td>
</tr>
<tr>
<td>Santa Barbara</td>
<td>Goleta Beach County Park</td>
</tr>
<tr>
<td>Santa Barbara</td>
<td>Arroyo Burro County Beach</td>
</tr>
<tr>
<td>Santa Barbara</td>
<td>Butterfly Beach</td>
</tr>
<tr>
<td>Santa Barbara</td>
<td>Summerland Beach</td>
</tr>
<tr>
<td>Santa Barbara</td>
<td>Santa Claus Beach</td>
</tr>
<tr>
<td>Santa Barbara</td>
<td>Carpinteria City Beach</td>
</tr>
<tr>
<td>Santa Barbara</td>
<td>La Conchita Beach</td>
</tr>
<tr>
<td>Ventura</td>
<td>Oil Piers Beach</td>
</tr>
<tr>
<td>Ventura</td>
<td>Hobson County Park</td>
</tr>
<tr>
<td>Ventura</td>
<td>North Rincon Parkway</td>
</tr>
<tr>
<td>Ventura</td>
<td>South Rincon Parkway/Emma Wood County Beaches</td>
</tr>
<tr>
<td>Ventura</td>
<td>Emma Wood State Beach</td>
</tr>
<tr>
<td>Ventura</td>
<td>Surfers Point Park</td>
</tr>
<tr>
<td>Ventura</td>
<td>San Buenaventura State Beach</td>
</tr>
<tr>
<td>Ventura</td>
<td>Pierpont Beach</td>
</tr>
<tr>
<td>Ventura</td>
<td>Oxnard Shores/Mandalay State Beach</td>
</tr>
<tr>
<td>Ventura</td>
<td>Hueneme Beach</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>Leo Carrillo State Park</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>Nicholas Canyon County Beach</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>Dan Blocker County Beach</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>Malibu Surfrider/Malibu Lagoon State Beach</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>Topanga County Beach</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>Will Rogers State Beach</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>Venice City Beach (Figure 17)</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>Dockweiller State Beach</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>Redondo County Beach</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>Redondo/Torrance County Beach</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>Long Beach City/Peninsula Beach</td>
</tr>
<tr>
<td>County</td>
<td>Location</td>
</tr>
<tr>
<td>-----------</td>
<td>-------------------------------------------------------</td>
</tr>
<tr>
<td>Orange</td>
<td>Surfside – Sunset Project</td>
</tr>
<tr>
<td>Orange</td>
<td>Huntington Cliffs</td>
</tr>
<tr>
<td>Orange</td>
<td>San Clemente</td>
</tr>
<tr>
<td>San Diego</td>
<td>South Oceanside/North County San Diego</td>
</tr>
<tr>
<td>San Diego</td>
<td>Carlsbad State Beach</td>
</tr>
<tr>
<td>San Diego</td>
<td>Agua Hedionda/Encinas</td>
</tr>
<tr>
<td>San Diego</td>
<td>South Carlsbad State Beach/Encinas Creek</td>
</tr>
<tr>
<td>San Diego</td>
<td>Batiquitos Lagoon Beach</td>
</tr>
<tr>
<td>San Diego</td>
<td>Leucadia State Beach</td>
</tr>
<tr>
<td>San Diego</td>
<td>Moonlight State Beach</td>
</tr>
<tr>
<td>San Diego</td>
<td>Cardiff State Beach/San Elijo Lagoon Beach</td>
</tr>
<tr>
<td>San Diego</td>
<td>Solana Beach/Fletcher Cove</td>
</tr>
<tr>
<td>San Diego</td>
<td>Del Mar City Beach/San Dieguito Lagoon Beach</td>
</tr>
<tr>
<td>San Diego</td>
<td>Torrey Pines State Beach</td>
</tr>
<tr>
<td>San Diego</td>
<td>Mission Beach</td>
</tr>
<tr>
<td>San Diego</td>
<td>Ocean Beach (San Diego)</td>
</tr>
<tr>
<td>San Diego</td>
<td>Coronado</td>
</tr>
<tr>
<td>San Diego</td>
<td>Imperial Beach</td>
</tr>
<tr>
<td>San Diego</td>
<td>Border Field State Park</td>
</tr>
</tbody>
</table>

Figure 17. **Venice Beach was identified as a Beach Erosion Concern Area.**  
*Source: Rachel Grandpre*
Box 7. Description of Problems for Selected Beach Erosion Concern Areas (CSMW 2010)

**Ocean Beach – San Francisco:** Chronic erosion has resulted in loss of recreational beach and damage to the city and Golden Gate National Recreation Area improvements. Erosion is especially severe along a 0.6-mile stretch where the Great Highway and the utilities beneath it are threatened.

**El Granada Beach (aka, Surfers Beach):** Bluff erosion at this high usage beach area occurs during high tides with intense storm waves causing accelerated erosion of the area, which in some cases is eating up two to three feet of coastline a year. There is no bluff erosion for approximately 1,000 feet south of the root of the East Breakwater because the bluff is protected by a revetment constructed by Caltrans. The rest (approximately 300 feet) is unprotected and does erode. Highway 1 is now protected by a revetment. Posts, guardrails, parking areas, and chunks of land are all gone along the stretch beach along Vallejo Beach, which extends from El Granada Beach.

**Southern Monterey Beaches:** Erosion of the beach and coastal dunes are affecting critical habitats and coastal access, and threatening public infrastructure such as a raw sewage transport pipeline for much of southern Monterey Bay. Passive erosion fronting areas of hardened shoreline will eventually prohibit lateral beach access through narrowing of the beach.

**Isla Vista:** Existing beach is inadequate in width and berm height throughout the year to support recreation use. Sea cliff toe is continually exposed to waves which threatens development and infrastructure.

**Carpinteria City Beach:** This beach is highly susceptible to storm erosion. Damages to the private property and public facilities will continue as a result of shoreline retreat, storm damage, and coastal flooding.

**South Rincon Parkway/Emma Wood State Beach:** Road and homes are subject to flooding and damage from overtopping waves during severe storm events. Passive erosion may be contributing to narrowing beach width that is caused by the presence of a seawall backing the beach.

**Hueneme Beach Park:** Local park facilities are subject to damage during high-wave conditions. Nourishment location and placement needs to be optimized to enhance longevity of sand on the beach before it is lost down Mugu Submarine Canyon.

**Nicholas Canyon County Beach:** The berm is inadequate in width and elevation to fully protect back-beach improvements from severe storm erosion. The natural outcrop at the downcoast end of beach provides limited sand retention capability. Complete loss of facilities is expected to occur.

**Malibu Surfrider/Malibu Lagoon State Beach:** Discharges from Malibu Creek meander laterally downcoast. The erosion channel cuts into the berm and has caused chronic erosion. The beach is inadequate in width and elevation to serve recreation demand and protect upland facilities and infrastructure from storm swell. There are no natural features to retain sand.

**Venice City Beach:** Venice Breakwater has formed a tombolo that acts as a terminal groin. The downcoast section of beach has adjusted by eroding. Loss of sand has exposed facilities and infrastructure to storm damage. Chronic erosion and storm exposure is expected to degrade with time. LA County expects that shortening the Venice Breakwater could remove its tombolo effect and establish a more stable shoreline configuration.

**Surfside – Sunset Project:** Chronic erosion due to the construction of the Anaheim Bay jetties has resulted in loss of recreational and protective beach through interruption of long-shore transport. Houses are subject to severe damage if the beach is not nourished periodically.
Box 7. Description of Problems for Selected Beach Erosion Concern Areas (CSMW 2010)

**Huntington Cliffs:** Lack of sediment supply from the Los Angeles and San Gabriel Rivers, and the construction of the Anaheim Bay Jetties combined with subsidence in the Huntington Oil Field have resulted in the loss of adequate recreational and protective beach width, and leave the bluffs susceptible to erosion. Health and safety are affected by inadequate and unsafe access, and unsightly and dangerous concrete rubble along the bluff toe. Bluff erosion rates have been estimated at 0.5 to 1.0 feet per year. Erosion threatens public lands occupied by parking, picnic areas, and a pedestrian and bike pathway.

**San Clemente:** Loss of shore protection and recreational beach width is a continuous problem for the city of San Clemente. Damages to coastal, residential, and commercial properties from storm-induced waves have become a serious threat. The railroad is often overtopped and damaged during high wave conditions. This is part of a completed USACE coastal storm damage reduction study.

**Solana Beach/Fletcher Cove:** Chronic erosion has resulted in the loss of the recreational beach, safety concerns, and damage to city improvements. Coastal Commission staff compiled an erosion rate at Solana Beach of 0 to 3.88 ft/yr. This is part of an ongoing USACE coastal storm damage reduction study along with the city of Encinitas.

**Del Mar City Beach/San Dieguito Lagoon Beach:** During severe winters, the protective beach is eroded and development behind the city beach is subject to flooding and damage. Location is heavily armored, but is often subject to damage and overtopping. Spit is susceptible to wave overwash, and some streets may also be flooded by the San Dieguito River.

Assessment of Long-Term Changes in Beaches along Southern California

The State of California provided funding to the University of California Marine Council for Coastal Environmental Quality Initiative to perform an assessment of the long-term erosion or accretion on beaches in the Southern California Bight (Point Conception to Mexican Border). The Bight, which is 260 miles long, includes five littoral cells. The assessment examined information, data, photographs, and LiDAR sets for 75 beaches over a period of 56 to 77 years before 2002 (Orme 2011).

As noted previously in this report, over the past century, many Southern California beaches have been affected, mostly negatively, by human actions originally designed to counter coastal erosion. These include seawalls, groins, breakwaters, jetties, dredging, and beach nourishment projects. Most of these beaches rely on sediment delivery from rivers, but roughly 50 percent of that sediment has been blocked by upstream dams. In addition, armoring of sea cliffs has reduced sand supply to these beaches.

In addition to the erosion-prevention actions noted above, two major climate patterns affect beach widths along the California coast over the longer term, individual El Niño Southern Oscillations and the Pacific Decadal Oscillation. These climate patterns are associated with multi-decade changes in water temperature, ocean levels, wave properties, precipitation, and sediment delivery to the shore.

The assessment found that relatively natural beaches uninfluenced by coastal engineering projects changed little (plus or minus 10 meters) between 1927 and 2002, being influenced by decadal scale climatic changes but little long-term erosion. Beaches influenced by hard and soft engineering projects have seen massive changes, and often these are of a transient nature, given the effects of El Niño and the
Pacific Decadal Oscillation. These findings are consistent with the findings by Hapke (2009), 40 percent of the State’s beaches were eroding in the early to late 1900s, increasing to 66 percent over the last 25 years.

The long-term chronic erosion of beaches, including beaches within eastern Santa Barbara, Santa Monica, northwestern San Pedro, and Oceanside littoral cells, is the result of indirect and direct human interference with the natural system. Indirectly, the loss of sediment from dam construction upstream of the coast has led to net beach erosion. Directly, seawalls, revetments, and bulkheads built to counter cliff erosion have led to passive beach erosion. Sediment trapped by jetties, groins, and breakwaters also has contributed to the erosion of beaches. The response has been to conduct sand by-passing and to nourish beaches.

In the absence of sand retention groins at nourished beaches, the assessment found that erosion of sand placed on beaches began soon after the placement, requiring continued placement on a relatively frequent basis. In view of the potential for sea level rise in the decades ahead, the authors concluded that artificially-filled beaches and those with a hardened back edge will likely experience passive erosion and gradual inundation. The authors concluded that policy makers should integrate a longer-term perspective into coastal management, especially regarding development, construction set-backs, and the advisability of continuing to nourish eroding beaches (Orme 2011).
3. SEA LEVEL RISE AND IMPLICATIONS FOR SHORELINE CHANGE

Sea Level Rise and Risks from Erosion for the California Shoreline

Sea level rise in this century and the potential impacts of increased erosion on the California shoreline have been assessed and reported by:

- The California Climate Change Center in *Impacts of Sea Level Rise on the California Coast* (Heberger et al. 2009), and

The NRC report is a result of California Executive Order S-12-08 that directed State agencies to plan for sea level rise and coastal impacts and that also requested the NRC to assess sea level rise to assist in the planning efforts. Oregon and Washington joined in the sponsorship, as well as USACE, The National Oceanic and Atmospheric Administration (NOAA), and the USGS.

The NRC report emphasized the enormous implications of sea level rise on valuable infrastructure, coastal development, loss of wetlands and habitat, and increased likelihood for flooding. One of the examples cited was the San Francisco Bay shoreline. Along central and southern San Francisco Bay are two international airports, the ports of San Francisco and Oakland, sports stadiums, housing developments, and a naval air station, much of which was built on fill material dredged from the Bay but only about 2 feet above the normal high tides. Flooding from sea level rise will begin with as little as 1.3 feet of sea level rise, which could occur within several decades. Box 8 describes an example of the types of damage associated with storms and rising sea levels.

**Box 8. Example of Coastal Storm Economic Damage (NRC 2012)**

A strong El Niño, combined with a series of large storms at times of high astronomical tides, caused more than $200 million dollars in damage (in 2010 dollars) to the California coast during the winter of 1982–1983 (Griggs et al. 2005). Higher sea levels and heavy rainfall caused flooding in low lying areas and increased the level of wave action on beaches and bluffs (Storlazzi and Griggs 2000). More than 3,000 homes and businesses were damaged, 33 oceanfront homes were completely destroyed, and roads, parks, and other infrastructure were heavily damaged.

Sea level rise along the coast of California is not uniform. Instead, it depends on a number of factors, primarily the extent of global sea level rise. The Intergovernmental Panel on Climate Change (IPCC) estimated that the global sea level rose an average of 1.7±0.5 mm per year over the 20th century (IPCC 2007). Rates for 1993 to 2003 were 3.1 ±0.7 mm per year, which were confirmed by satellite imagery and tide gauges. Satellite data on sea level rise now extend from 1993 to 2013, but were not yet available as this document was being prepared.
Sea levels are rising as a result of the warming climate and the associated warming of the oceans, which together are melting land ice and causing thermal expansion of the sea water. Other factors that influence the extent of sea level rise include the water withdrawn from aquifers and water stored behind dams. The factors that affect ocean levels along the California shoreline also include climate patterns, such as the ENSO, which affect winds and ocean circulation, raising local sea levels during warm phases (El Niño), and lowering sea level during cool phases (La Niña) (Box 9). For example, large El Niños can raise coastal sea levels by 10 to 30 cm during the winter months.

Another phenomenon affecting sea levels along the California shoreline is called a sea level fingerprint. As ice melts, the runoff enters the ocean, and the land and ocean basins both deform as a result of the loss of land ice, causing gravitational effects that produce a spatial pattern of regional sea level change. Melting in Alaska, and to a lesser extent in Greenland, causes the relative sea level along the California Coast to fall, whereas melting from Antarctica causes rising sea levels. The net effect of the three sources is a reduction in sea level rise of 24 percent along the central coast (slightly higher on the northern coast) and 14 percent along the southern coast.

Projected Sea Level Rise for California Shoreline

The NRC’s projected rise in sea levels for the California shoreline for the years 2030, 2050, and 2100 is shown in Box 10. These estimates include the effects of the above noted local factors using the global information rates for sea level rise and take into account the changes in elevation of the shoreline over time.

Changes in the elevation of the land along coastal California are a result of separate vertical land motion forces.

1. Subsidence of 1–2 mm per year of the California land mass is occurring as a result of the melting and disappearance of the North American ice sheets of 20,000 years ago.
2. Tectonics is causing regional uplift on the Northern California coast where ocean plates are descending below the Cascadia Subduction Zone. South of Cape Mendocino, the Pacific and North American plates are sliding past one another along the San Andreas Fault Zone creating little vertical land motion.
3. Sediment compaction may reduce the volume of the sediments and thus result in subsidence, particularly for peat- and mud-rich estuaries and tidal marshes. Little information or data are available.
4. Water or hydrocarbon extraction can lower surface elevations up to tens of centimeters per year depending on if replacement fluids are returned to the subsurface.
The overall land motion is that land north of Cape Mendocino is rising at 1.5 to 3.0 mm per year, and land south of Cape Mendocino is sinking at 1 mm per year. These are confirmed by GPS measurements.

An earthquake with a magnitude of 8 or greater along the Cascadia Subduction Zone could suddenly raise sea level along parts of the coast by an additional 1 to 2 meters (3 to 7 feet) over projected levels north of Cape Mendocino.

Uncertainty exists in the predictions, primarily regarding future ice losses, constant rates of vertical land motion, ocean dynamics, and the need to make assumptions about future conditions that drive the ocean models for global sea level rise (e.g., input data regarding future greenhouse gas emissions resulting from such sources as population growth, technological improvements, or large volcanic eruptions). Uncertainties grow as the period of projection lengthens, and the NRC report noted that confidence was high for 2030 and perhaps 2050. For 2100, the confidence was only that sea level rise will fall within the uncertainty bounds, reflected in the ranges of sea level rise shown in Box 10. However, the message is clear:

*The California shoreline will experience a rise in the level of the seas, and there will be significant impacts to physical, biological, and economic resources along the shoreline and inland bays, primarily due to erosion of dunes, beaches, and cliffs/bluffs, loss of marshes/wetlands, flooding, increasing salinity in estuaries, and changing habitats for animal and plant life.*

The NRC report noted that most of the damage to the shoreline to date has been the result of large waves and storm surges that, when combined with high tides, have produced short-term sea levels exceeding the mean sea levels projected for 2050. The NRC report also stated that there is no consensus among climate model simulations about whether the number and severity of storms will change in the Pacific northeast. Some models predict a northward shift in North Pacific storm tracks, and, if so, winter storm impacts may decrease in Southern California (Box 11 and 12.) The NRC report did recognize that extreme events can raise water levels much faster than the rates of sea level rise projected for the shoreline. Unusually high sea levels may occur when major storms coincide with high astronomical tides, and especially during years when sea levels are heightened during El Niños. As sea levels rise, the number of extreme events is expected to increase. Thus, any increase in storminess or in the number of rare extreme storms is potentially a larger problem for the U.S. West Coast than the climate-driven rise in sea level, at least for the next several decades (NRC 2012).
Erosion due to Sea Level Rise

The net result of sea level rise and coastal erosion is shoreline retreat, from a few centimeters per year for cliffs of bedrock to several meters per year for beaches, dunes, and unconsolidated bluffs and cliffs. The actual on-site rates would certainly vary depending on such factors as local geology, offshore bathymetry, and wave climates.

The extent of erosion on the shoreline from sea level rise depends on the coastal topography, and geomorphology (and the extent of armoring). These are the result of a collision between the North American and Pacific plates that began about 30 million years ago. About 28 percent of the shoreline is relatively flat, comprising wide beaches, sand dunes, bays, estuaries, and wetlands. The other 72 percent is made up of sea cliffs.

The NRC noted that few studies have projected future shoreline and sea cliff retreat rates under rising sea levels. Because projected rates of sea level rise are expected to be moderate in the near term, extrapolation of current erosion rates is likely reasonable to at least 2030. Where data are available, site-specific estimates can be made by using existing erosion trends and incorporating future sea level rise and potential increases in storm wave heights and frequency.

The Pacific Institute (Phillip Williams and Associates 2009) concluded that the California coast has experienced 20 cm (8 inches) of sea level rise over the past century, and that the mean sea level is expected to rise from 1 meter to 1.4 meters (3.3 to 4.6 feet) by the year 2100. Their approach to estimate shoreline erosion uses the rates of shoreline change to the coastal geology, and then applies changes in total water level at the shoreline in exceedance of the elevation of the base of the bluff or cliff to predict erosion.
Based on this approach, the Central and Northern California coast is projected to lose 41 square km of land by 2100 relative to 2000 for 1.4 meters (4.6 feet) of sea level rise. Table 7 shows the overall loss of area due to erosion of dunes and cliffs for a rise of 1.4 meters (4.6 feet) in 2100 (Phillip Williams and Associates 2009; Heberger et al. 2009).

Estimates of the effects of erosion from sea level rise show that cliffs will erode and retreat an average distance of 66 meters by 2100 and dunes will erode and retreat an average of about 170 meters by 2100 (Table 8).

Erosion of dunes and cliffs depend on site-specific factors; for example, in Del Norte County, cliffs are projected to erode a maximum distance of 520 meters.

Precise projections of future beach retreat or erosion in these areas are highly uncertain given the uncertainties in exactly how sandy shorelines with back-beach barriers or armor will respond to sea level rise combined with uncertainties in rates of future sea level rise and in the future storminess (NRC 2012).

Table 7. Erosion with a 1.4-m sea level rise, by county.


<table>
<thead>
<tr>
<th>County</th>
<th>Dune erosion (sq. miles)</th>
<th>Cliff erosion (sq. miles)</th>
<th>Total erosion (sq. miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Del Norte</td>
<td>1.9</td>
<td>2.6</td>
<td>4.5</td>
</tr>
<tr>
<td>Humboldt</td>
<td>3.7</td>
<td>2.4</td>
<td>6.1</td>
</tr>
<tr>
<td>Marin</td>
<td>1.0</td>
<td>3.7</td>
<td>4.7</td>
</tr>
<tr>
<td>Mendocino</td>
<td>0.74</td>
<td>7.5</td>
<td>8.3</td>
</tr>
<tr>
<td>Monterey</td>
<td>1.9</td>
<td>2.5</td>
<td>4.4</td>
</tr>
<tr>
<td>San Francisco</td>
<td>0.23</td>
<td>0.30</td>
<td>0.53</td>
</tr>
<tr>
<td>San Luis Obispo</td>
<td>1.4</td>
<td>1.5</td>
<td>2.9</td>
</tr>
<tr>
<td>San Mateo</td>
<td>0.82</td>
<td>2.4</td>
<td>3.2</td>
</tr>
<tr>
<td>Santa Barbara</td>
<td>0.62</td>
<td>1.9</td>
<td>2.6</td>
</tr>
<tr>
<td>Santa Cruz</td>
<td>0.87</td>
<td>0.9</td>
<td>1.8</td>
</tr>
<tr>
<td>Sonoma</td>
<td>0.60</td>
<td>1.6</td>
<td>2.2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>14</strong></td>
<td><strong>27</strong></td>
<td><strong>41</strong></td>
</tr>
</tbody>
</table>
**Table 8. Retreat due to erosion for cliffs and dunes, by county, in 2100.**
*Source: Phillip Williams and Associates 2009; Heberger et al. 2009*

<table>
<thead>
<tr>
<th>County</th>
<th>Dune erosion</th>
<th>Cliff erosion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average distance (m)</td>
<td>Maximum distance (m)</td>
</tr>
<tr>
<td>Del Norte</td>
<td>180</td>
<td>400</td>
</tr>
<tr>
<td>Humboldt</td>
<td>160</td>
<td>600</td>
</tr>
<tr>
<td>Marin</td>
<td>140</td>
<td>270</td>
</tr>
<tr>
<td>Mendocino</td>
<td>190</td>
<td>440</td>
</tr>
<tr>
<td>Monterey</td>
<td>180</td>
<td>400</td>
</tr>
<tr>
<td>San Francisco</td>
<td>150</td>
<td>230</td>
</tr>
<tr>
<td>San Luis Obispo</td>
<td>140</td>
<td>330</td>
</tr>
<tr>
<td>San Mateo</td>
<td>230</td>
<td>430</td>
</tr>
<tr>
<td>Santa Barbara</td>
<td>190</td>
<td>320</td>
</tr>
<tr>
<td>Santa Cruz</td>
<td>170</td>
<td>340</td>
</tr>
<tr>
<td>Sonoma</td>
<td>150</td>
<td>320</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>170</strong></td>
<td><strong>370</strong></td>
</tr>
</tbody>
</table>

The Pacific Institute also estimated the risks of erosion to transportation-related infrastructure (Table 9).

**Table 9. Miles of roads and railways vulnerable to 100-year floods now and with a 1.4-meter sea level rise along the California coast.**
*Source: Phillip Williams and Associates 2009; Heberger et al. 2009*

<table>
<thead>
<tr>
<th>By County</th>
<th>Highways (miles)</th>
<th>Roads (miles)</th>
<th>Railways (miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Current risk</td>
<td>Risk with 1.4-m sea level rise</td>
<td>Current risk</td>
</tr>
<tr>
<td>Del Norte</td>
<td>6.6</td>
<td>8.2</td>
<td>59</td>
</tr>
<tr>
<td>Humboldt</td>
<td>37</td>
<td>58</td>
<td>120</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>14</td>
<td>31</td>
<td>42</td>
</tr>
<tr>
<td>Marin</td>
<td>1.2</td>
<td>4.1</td>
<td>22</td>
</tr>
<tr>
<td>Mendocino</td>
<td>5.6</td>
<td>7.9</td>
<td>28</td>
</tr>
<tr>
<td>Monterey</td>
<td>27</td>
<td>31</td>
<td>85</td>
</tr>
<tr>
<td>Orange</td>
<td>32</td>
<td>48</td>
<td>340</td>
</tr>
<tr>
<td>San Diego</td>
<td>0.62</td>
<td>8.0</td>
<td>12</td>
</tr>
<tr>
<td>San Francisco</td>
<td>0.20</td>
<td>0.37</td>
<td>17</td>
</tr>
<tr>
<td>San Luis Obispo</td>
<td>5.3</td>
<td>7.4</td>
<td>10</td>
</tr>
<tr>
<td>San Mateo</td>
<td>3.4</td>
<td>5.0</td>
<td>23</td>
</tr>
</tbody>
</table>
In regard to the property that lies within the potential erosion hazard zone, the Pacific Institute estimates are shown in Table 10 for 11 coastal counties. The estimates are based on property parcels, given that is the method used by counties to assess taxes. The estimate is that 10,000 parcels lie within the erosion zone, of which 66 percent are completely in the hazard zone meaning they would be totally lost. The other 34 percent are expected to be partially lost to erosion. Using the average cost of $1.4 million per parcel. Note: this value is quite variable with property in the northern region and northern parts of the central region being less, and property in the southern region and southern parts of central California region being more. The economic impact of lost property from erosion is expected to be near $14 billion.

Table 10. Number of Properties within the Erosion Zone Hazard Zone with a 1.4-m sea level rise.

<table>
<thead>
<tr>
<th>County</th>
<th>Number of parcels*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Del Norte</td>
<td>No data</td>
</tr>
<tr>
<td>Humboldt</td>
<td>570</td>
</tr>
<tr>
<td>Marin</td>
<td>1,300</td>
</tr>
<tr>
<td>Mendocino</td>
<td>No data</td>
</tr>
<tr>
<td>Monterey</td>
<td>1,600</td>
</tr>
<tr>
<td>San Francisco</td>
<td>850</td>
</tr>
<tr>
<td>San Luis Obispo</td>
<td>No data</td>
</tr>
<tr>
<td>San Mateo</td>
<td>1,900</td>
</tr>
<tr>
<td>Santa Barbara</td>
<td>580</td>
</tr>
<tr>
<td>Santa Cruz</td>
<td>3,000</td>
</tr>
<tr>
<td>Sonoma</td>
<td>500</td>
</tr>
<tr>
<td>Total</td>
<td>10,000</td>
</tr>
</tbody>
</table>

*The estimates do not take into account any management responses to sea level rise such as armoring, and the majority of the Southern California coast was excluded because of the number of ongoing initiatives on climate change and coastal hazards mapping. Mapping (i.e., identifying locations) in Southern California will likely lead to the installation of new armoring and strengthening of existing armoring, given the economic value of the infrastructure and industries at risk.
Table 11 shows the population at risk from erosion with a 1.4-meter rise in sea level in 2100. In the 11 coastal counties north of Santa Barbara, 14,000 people live within areas vulnerable to erosion (Phillip Williams and Associates 2009; Heberger et al. 2009).

### Table 11. Population vulnerable to erosion from a 1.4-m sea level rise.

<table>
<thead>
<tr>
<th>County</th>
<th>Erosion-related Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Del Norte</td>
<td>620</td>
</tr>
<tr>
<td>Humboldt</td>
<td>580</td>
</tr>
<tr>
<td>Marin</td>
<td>570</td>
</tr>
<tr>
<td>Mendocino</td>
<td>930</td>
</tr>
<tr>
<td>Monterey</td>
<td>820</td>
</tr>
<tr>
<td>San Francisco</td>
<td>1,200</td>
</tr>
<tr>
<td>San Luis Obispo</td>
<td>1,100</td>
</tr>
<tr>
<td>San Mateo</td>
<td>2,900</td>
</tr>
<tr>
<td>Santa Barbara</td>
<td>2,100</td>
</tr>
<tr>
<td>Santa Cruz</td>
<td>2,600</td>
</tr>
<tr>
<td>Sonoma</td>
<td>300</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>14,000</strong></td>
</tr>
</tbody>
</table>

Throughout most of the state, flood risk exceeds the risk from erosion, but in some counties, coastal erosion poses a greater risk, as noted previously. A 1.4-meter rise in sea level will put 480,000 people at risk of a 100-year flood event, given today’s population; the cost of replacing property (i.e., buildings and contents) at risk of coastal flooding is estimated to be nearly $100 billion (in 2000 dollars). About 2/3 of that property is concentrated in the San Francisco Bay area (Herberger et. al 2009).

As one part of a possible coastal protection strategy, about 1,100 miles of new or modified coastal protection structures may be needed on the coast and in areas of San Francisco Bay. The costs of building seawalls and bulkheads to protect some vulnerable areas will total at least $14 billion with added maintenance costs of $1.4 billion per year.

**Summary Erosion and Sea level rise**

By 2100, sea level is projected to rise south of Cape Mendocino somewhere in the range of 1.5 feet to 5.5 feet, and north of Cape Mendocino 4 inches to 4.7 feet. The Pacific Institute study found that a 5.5-feet rise in sea level will put 480,000 people at risk of a 100-year flood event, given today’s population, and the cost of replacing property at risk of coastal flooding is estimated to be nearly $100 billion (in 2000 dollars).

Sea level rise will exacerbate erosion of the coastline. California’s cliffs and bluffs are eroding at a rate of about 2 centimeters to 30 centimeters per year. The rate depends on local site conditions, such as topography and whether the cliffs and bluffs are unconsolidated sedimentary materials or resistant bedrock. The response to date has been to armor much of the shoreline, but, these will eventually be inundated due to sea level rise and possible increased storminess giving rise to more erosive conditions. It is expected that more armoring will be installed to protect property, but those “protections” may have negative effects on beaches due to passive erosion.
Tidal marshes and mudflats protect inland areas from flooding and wave damage, through such mechanisms as eelgrass slowing currents or marsh vegetation reducing wave height and energy. Tidal marshes and mudflats can only survive sea level rise if they either migrate inland or if they can build elevation through adequate sediment supply that keeps pace with the rising sea level. Migration inland is a function of the local topography and having unobstructed pathways to move inland. Storms are important for delivery of sediments to marshes and mudflats, but entrapment of sediment behind coastal dams and armoring of the shoreline have reduced the sediment supply, making marshes less likely to survive, especially in Northern California.

**State of California’s Sea-Level Rise Guidance Document**

In October 2010, the Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT) finalized the *State of California Sea-Level Rise Interim Guidance Document* (*Interim Guidance Document*), the purpose of which was to assist state agencies to plan for sea level rise and other climate change impacts.

In March 2013, the 2010 Guidance was updated to reflect the findings and conclusions in the NRC 2012 report. The underlying premise of the 2013 SLR Guidance (California 2013) is that sea level rise potentially will cause many harmful economic, ecological, physical, and social impacts, and incorporating sea level rise into agency decisions can help mitigate some of these potential impacts.

**RECOMMENDATIONS IN THE 2013 CALIFORNIA SEA LEVEL RISE GUIDANCE**

1. Use the ranges of SLR presented in the June 2012 National Research Council report on Sea-Level Rise for the Coasts of California, Oregon, and Washington as a starting place and select SLR values based on agency and context-specific considerations of risk tolerance and adaptive capacity.
2. Consider timeframes, adaptive capacity, and risk tolerance when selecting estimates of SLR.
3. Consider storms and other extreme events.
4. Coordinate with other state agencies when selecting values of SLR and, where appropriate and feasible, use the same projections of sea level rise.
5. Future SLR projections should not be based on linear extrapolation of historic sea level observations.
6. Consider changing shorelines.
7. Consider predictions in tectonic activity.
8. Consider trends in relative local mean sea level.

4. ECONOMIC AND SOCIAL IMPACTS OF EROSION AND ACCRETION

Of California’s 1,100 miles of shoreline, there are 650 miles of lower-relief cliffs and bluffs that typically are eroded into marine terraces; 140 miles of high-relief cliffs and coastal mountains, and 310 miles of low-relief beaches, dunes, and wetlands (Hapke et al. 2006). If coastal features like beaches and bluffs were unused and uninhabited, erosion would have little economic or social consequence for the State. But California’s shorelines are a critical resource; residents and tourists use the beaches for recreation (e.g. surfing, jogging, birding, swimming), shorelines are prime real estate for residences, numerous businesses depend on resources accessible from the shoreline (e.g., fishing, boating, mineral extraction, shipping), and shoreline habitats are essential for multitudes of animal and plant species, which also contribute to the economic and social wellbeing.

Together, these recreational and commercial uses generate substantial revenues for local communities and the State; over $44 billion in 2013 (NOAA ENOW 2017). Additionally, the coast is the most popular place to live and work. Approximately 80 percent of Californians live within 30 miles of the coast (Griggs 1999), and three of the ten most populous cities in America are located on the California shoreline: Los Angeles, San Jose (i.e., along San Francisco Bay shoreline), and San Diego.

Although California has the largest coastal economy\footnote{Coastal Economy data includes all activities and industries reported by the Bureau of Labor Statistics for the coastal counties.} in the nation (NOEP 2017), the combination of population, coastal processes, and economic activity tends to focus the discussion of economic and social impacts on the central and southern regions of the State. The ocean economies\footnote{Ocean economy data include only ocean related activities and industries.} of all three regions (northern, central, and southern) rely heavily on tourism and marine transport. However, they exhibit differences in total employees, wages, and gross domestic product.

Environmental variables, such as climate and water temperature, make Southern California a popular place to live, visit, and recreate. These favorable conditions may contribute to that region’s ocean economy being

![Figure 18. Ocean-based GDP in 2013 (NOAA ENOW 2017).]
more than $10 billion larger than that of the northern and central regions combined ($27 billion versus $16 billion in 2013) (NOAA ENOW 20179). Although studies have shown that the northern region is experiencing the highest rates of erosion in the State (Hapke et al. 2009), there are few documented social and economic impacts because of sparser development and fewer recreational opportunities. By far, the social and economic impacts of shoreline change are better documented for the central and southern shorelines of the State.

The social and economic implications of erosion and accretion in California were examined through a literature review, data search, and discussions with the California Coastal Sediment Management Workgroup. The scope of the research on costs was limited to the cost of beach nourishment reported by state and federal agencies. However, during the research process, information was found on other costs and has been included in this report.

Social Impacts

Social impacts occur when societal benefits are directly affected by erosion, such as loss of beach quality (e.g., area, sand quality, and wave quality) and associated recreational uses, loss of private property, and damage to infrastructure. There are few documented impacts of accretion along ocean-facing shorelines in California, although accretion (typically from upstream sediment transport) commonly affects navigation channels along sheltered shorelines by restricting access through the mouths of bays, inlets, and harbors, and by requiring periodic dredging. This study found that social impacts are often manifested in response to the methods undertaken to control shoreline change. Shoreline management practices bring to the surface social and economic conflicts because of the trade-offs between public and private interests as well as the trade-offs between users within these sectors and their perceptions of how shoreline management methods best serve their interests.

Beach recreation is a large part of the California economy and is also a large part of the social fabric of daily life, especially for Southern Californians. Social impacts are more difficult to quantify than economic impacts and are best illustrated through case studies. Case studies presented in this report illustrate the social challenges that have arisen in managing changing shorelines. They often show that measures undertaken for one purpose may be incompatible with others. Some of the social impacts in the case studies include:

- *Public beach access blocked or reduced by shoreline armoring.* Exemplified in the Broad Beach case study, shore-parallel armoring, installed to protect infrastructure or private property, can prevent the public from accessing the beach. The State is mandated to protect public access to the shore (Article X Section 4 of the State Constitution, California Coastal Act), but private property owners have clashed with the public over access issues for decades in California.

- *Loss of beach recreational opportunities because of armoring and changes in surf.* Surfing experiences, as illustrated in two case studies, can be altered by structures built perpendicular or parallel to the shore. One case study showed that recreational losses can be reversed: Santa Cruz

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9 Economics: National Ocean Watch (ENOW) is annual time-series data that describes six economic sectors that depend on the resources of the oceans and Great Lakes: living resources, offshore mineral resources, marine transportation, marine construction, ship and boat building, and tourism and recreation.
County saw an increase in beach attendance when riprap was removed from the beach and replaced with a bluff stabilization method, which improved aesthetics and beach access. At Surfers Point, managed retreat is contributing to maintenance of the beach and surf break.

- **Aesthetic impacts.** Ocean Beach and Pleasure Point are two examples of many along the California coast where armoring may diminish the quality of the experience of beachgoers. Rubble from damaged seawalls or riprap can be unsightly and can interfere with or otherwise detract from views both from the water and the beach. Methods are being used in California to help mitigate this issue, but more aesthetically pleasing options for erosion control are not always feasible or available (Figure 19, 20, and 21).

![Figure 19 and Figure 20. Stone revetments were installed at Monterey’s Ocean House Apartments in 1986 and removed in 1994, to be replaced by a seawall of reinforced concrete and steel girder support shown in Figure 19. Source: R.L. Weigel](image)

![Figure 21. Seawall protecting Monterey Ocean Harbor House Apartments. Source: Gary Griggs](image)
Economic Impacts

This report examines the recreational value of beaches. The loss of beach width (which affects the public’s ability to recreate at the beach) and associated loss of revenue was quantified in a study modeling welfare benefits in San Clemente (Pendleton et al. 2011). The study predicted that a 50-percent increase in beach width could generate $3.1 million in consumer surplus per year at this site. At one beach in San Diego, it was estimated that maintaining current beach width could result in over $300 million in increased revenue for local vendors. Increasing the width of the beach commensurate with the rate of population increase would generate almost half a billion dollars in revenue (King 2001). A study of another beach estimated that lack of sand at beaches could reduce the value of a beach trip by 15 percent (Lew and Larson 2004).

The economic impact of beach recreation is generally evaluated in support of cost-benefit analyses for proposed coastal storm damage reduction projects. The revenue figures from these studies are not easily transferrable across locations because of site-specific attributes. However, they do provide a useful range of potential economic impacts due to erosion impacts and loss of beaches in similar places.

Quantification of costs attributable to shoreline erosion control, specifically beach nourishment and, to a lesser extent, shoreline armoring, were the two primary costs of shoreline change examined in this report, and the two most common responses in the State of California. Tabulation of expenditure information for these approaches involved a number of challenges, and this report acknowledges several obstacles in attempting to calculate the total costs of managing shoreline change including:

- The definition of nourishment is not always straightforward. The USACE often places maintenance dredged material on nearby beaches. The USACE considers this to be beneficial use. This type of sand deposition on beaches is technically not considered nourishment, even though this practice has beach nourishment value. The distinction used by USACE between nourishment and beneficial use depends on the purpose of the project; whether the purpose is beach nourishment or navigation dredging.

- Port and harbor expenditures on dredging are not centralized, in each of the USACE District offices. They must be individually extracted from maintenance and operational budgets. The data on nourishment costs borne by the federal government are also not centrally filed, nor easy to extract.

- Although armoring of private property is a common practice in California, information on the costs associated with seawalls, nourishment, mitigation fees, and structural repairs is not readily available.

- Similarly, local and regional spending on armoring, nourishment, or retreat must be individually extracted from town, city, or county budget reports.

- Non-market values are difficult to quantify. Systematic studies are not available to enable temporal and spatial comparable trends in social and other non-market value impacts statewide.

- Information is not generally available on the costs of alternative strategies (e.g., installation of artificial reefs), the costs of managed retreat, and the cost of abandonment strategies.

Despite these challenges, the costs of shoreline change in California (based on the information gathered) can be summarized as follows:
• **Costs of shoreline hard armoring** (borne by private property owners, and local and state government): With approximately 10 percent of California’s shoreline armored (136 miles of seawalls), a rough estimate of construction costs *that have been spent* for armoring falls somewhere in the range of approximately $350 million to $7 billion, not including reconstruction or maintenance costs or the costs of secondary impacts. Today’s costs would be much higher, somewhere around $5,000 per foot and higher, depending on the local site characteristics.

• **Costs of nourishment** (borne by local, regional, state, and federal government): From 1984–2010, more than $67 million was spent to nourish California beaches according to the California Department of Boating and Waterways (2011). The USACE has expended $48 million on nourishment projects since 1990 (Los Angeles and San Francisco Districts, 2012) for estimated total beach nourishment cost in the State of at least $115 million since 1984. Two projects in San Diego, sponsored by SANDAG, one in 2001 and the other in 2012, cost $9 per cubic yard and $20 per cubic yard, respectively. These were dedicated sand-dredging projects that placed the dredged material directly on the beaches.

**Methods**

To better understand the social and economic effects of shoreline change, the following questions were used to guide this study:

- What are the social and economic effects of erosion and accretion in California?
- What trends are emerging and what, if any, conclusions can be drawn?
- Are there any obvious policy implications for what has been learned?

This review of economic and social impacts of erosion consisted of three main components. The first component, an annotated bibliography was prepared that includes articles, reports, and other forms of literature extracted from academic databases, government and non-government websites, and the popular press. Recommended points of contact at state and federal agencies were also consulted to gather relevant literature. Over 90 technical papers in the literature were researched and annotated, the majority of them relating to coastal erosion responses along the Southern California shoreline.

Discussions with recommended points of contact in conjunction with reviews of popular press articles led to the development of fifteen case studies. These case studies serve as examples of the types of social and economic impacts of erosion and accretion occurring in California. Although attempts were made to locate relevant case studies for every sub-region, the majority of case studies are focused on the central and southern shoreline. The California Coastal Sediment Management Workgroup reviewed the case studies and their feedback was incorporated. The California Coastal Sediment Management Workgroup was also provided with the references for the annotated bibliography and workgroup members suggested additional literature.

Cost information for beach nourishment projects was gathered from state and federal sources. The California Coastal Commission had assembled a database of local and state projects in 2000 from a variety of sources and databases. Only entries containing cost and dredging information in the comprehensive database were included.
database were included in this report; entries related to sand bypassing projects were placed in a separate table (Appendix C).

To the extent possible, the information was organized and evaluated in the northern, central, and southern regions.

**Summary of Differences between the Three Regions**

The economic and social impacts of erosion and accretion along the California coast are linked to geologic features and coastal processes occurring there. These environmental variables create distinct regions, and the economic and social issues associated with erosion are distinguishable along these same boundaries.

All three regions’ ocean economies rely heavily on recreation and tourism and commercial marine transportation. Those two sectors alone combined to make up two-thirds of each region’s ocean economy in 2013. Living resources, marine construction, offshore mineral resources, and ship and boat building contributed to approximately 33 percent of the goods and services produced in each of the three regions. Despite these similarities, the three regions exhibit differences in total employees, wages, and Gross Domestic Product (GDP) within their respective ocean sector economies. While the northern part of the State employed almost 27,000 people in ocean-dependent jobs in 2013, Southern California employed more than ten times that number, 270,000. On a per capita basis, two percent of the populations in all three regions worked in ocean-dependent jobs. However, average wages differed: the average ocean-sector employee in Northern California earned $26,000 in 2013, while employees in Central California earned $32,600 and in Southern California $43,700 (Figure 22).

Ocean-dependent wages in Southern California were slightly higher than the national average of $39,000.

The northern and southern ocean economy similarities can be seen in each region’s ocean-dependent GDP (Figure 22):

- Northern California generated $1.4 billion in 2013, or about $1,020 per person
- Central California generated about $15 billion in 2013, or about $1,500 per person
- Southern California generated $27 billion in 2013, or about $1,600 per person

While ocean-dependent tourism and recreation together account for the largest portion of each region’s ocean GDP, the differences in weather allow for an ocean economy in Southern California with little seasonality when compared to the north. Central California’s ocean-dependent economy overshadows Northern California’s ocean-dependent economy, and Southern California’s ocean-dependent economy dwarfs both of them. Therefore, the potential economic impacts of erosion in the State of California, if left unaddressed, could have significant economic consequences, particularly in the southern region.

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10 Northern region: Del Norte County, Humboldt County, Marin County, Mendocino County, Napa County, Sonoma County, Yolo County. Central: Alameda County, Contra Costa County, Monterey County, Sacramento County, San Francisco County, San Joaquin County, San Mateo County, Santa Clara County, Solano County, San Luis Obispo County, Santa Barbara County, Santa Cruz County. Southern: Los Angeles County, Orange County, San Diego County, Ventura County.
Figure 22. Regional GDP, employees, and average earnings\textsuperscript{11}.
Source: NOAA ENOW 2017

\textsuperscript{11} Ocean economy includes establishments that are either: (1) in an industry whose definition explicitly ties the activity to the ocean or (2) in an industry that is partially related to the ocean and is located in a shore-adjacent zip code. Sectors include tourism and recreation, ship and boat building,
According to Clayton (1991) and Wiegel (1994) (as cited in Campbell and Benedet 2006), approximately 85 percent of beach nourishment activity is taking place in the southern part of the State (Point Conception to the Mexican Border). The extent of roads within a quarter-mile of the shoreline is a reflection of this higher degree of development; in the south, 1,678 miles of roads occur within a quarter-mile of the shoreline, compared to the northern region, with only 440 miles of roads within the same distance.

Table 12 provides coastal regional characteristics. Greater populations, denser development (including infrastructure), and a large ocean economy all make Southern California particularly vulnerable to economic and social impacts from shoreline change compared to Central and Northern California.

Table 12. Coastal regional characteristics

<table>
<thead>
<tr>
<th>Regions*</th>
<th>Coastal Population 2000 (1,000's)**</th>
<th>Coastal Share of Regional Population (%)</th>
<th>Roads Within 0.25 Miles of Shoreline (miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern</td>
<td>36</td>
<td>14.9</td>
<td>440</td>
</tr>
<tr>
<td>Bay Area (Bay Side)</td>
<td>439</td>
<td>6.5</td>
<td>936</td>
</tr>
<tr>
<td>Bay Area (Ocean Side)</td>
<td>37</td>
<td>1.7</td>
<td>798</td>
</tr>
<tr>
<td>Central</td>
<td>65</td>
<td>5</td>
<td>773</td>
</tr>
<tr>
<td>Southern</td>
<td>169</td>
<td>1.1</td>
<td>1,678</td>
</tr>
<tr>
<td>Total</td>
<td>747</td>
<td>3.1</td>
<td>4,625</td>
</tr>
</tbody>
</table>

Additional differences between the regions can be gleaned from the disparity between miles of seawall found along northern, central, and southern shorelines (Table 13). For example, Ventura County, in Southern California, contains nearly 26 miles of seawalls. This amounts to over 60 percent of the County’s coast being armored. Rates seen in the northern region are typically less than 5 percent of any county’s shoreline (Table 13).

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12 *Northern Coast includes: Del Norte, Humboldt, Mendocino; Bay Area (Ocean Side) includes: Sonoma, Marin, San Francisco, San Mateo; Bay Area (Bay Side) includes these counties plus Napa, Solano, Contra Costa, Alameda, Santa Clara; central coast includes: Santa Cruz, Monterey, San Luis Obispo, Santa Barbara; Southern Coast includes: Ventura, Los Angeles, Orange, San Diego.

**Coastal population is the population in census block groups bordering the shoreline. In densely populated areas, blocks extend 0.1 to 0.25 miles inland. In more rural areas, they can extend as far as 10 to 20 miles inland.
Table 13. Armoring by region.
Source: PPIC 2008

<table>
<thead>
<tr>
<th>County</th>
<th>Region</th>
<th>Miles of Seawall*</th>
<th>Share of Shoreline (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Del Norte</td>
<td>Northern</td>
<td>2.2</td>
<td>4.6</td>
</tr>
<tr>
<td>Humboldt</td>
<td>Northern</td>
<td>1.8</td>
<td>1.1</td>
</tr>
<tr>
<td>Mendocino</td>
<td>Northern</td>
<td>0.7</td>
<td>0.5</td>
</tr>
<tr>
<td>Sonoma</td>
<td>Northern</td>
<td>0.9</td>
<td>1.5</td>
</tr>
<tr>
<td>Marin</td>
<td>Central</td>
<td>1.9</td>
<td>1.9</td>
</tr>
<tr>
<td>San Francisco</td>
<td>Central</td>
<td>2.4</td>
<td>45.1</td>
</tr>
<tr>
<td>San Mateo</td>
<td>Central</td>
<td>4.9</td>
<td>8.3</td>
</tr>
<tr>
<td>Santa Cruz</td>
<td>Central</td>
<td>11.3</td>
<td>24.8</td>
</tr>
<tr>
<td>Monterey</td>
<td>Central</td>
<td>4.5</td>
<td>3.7</td>
</tr>
<tr>
<td>San Luis Obispo</td>
<td>Central</td>
<td>6.5</td>
<td>5.7</td>
</tr>
<tr>
<td>Santa Barbara</td>
<td>Southern</td>
<td>14.3</td>
<td>12.4</td>
</tr>
<tr>
<td>Ventura</td>
<td>Southern</td>
<td>25.7</td>
<td>61.1</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>Southern</td>
<td>17.5</td>
<td>15.9</td>
</tr>
<tr>
<td>Orange</td>
<td>Southern</td>
<td>16.7</td>
<td>36.8</td>
</tr>
<tr>
<td>San Diego</td>
<td>Southern</td>
<td>24.7</td>
<td>31.5</td>
</tr>
<tr>
<td>California</td>
<td></td>
<td></td>
<td>136</td>
</tr>
</tbody>
</table>

* Includes: bluff walls, bulkheads, revetments, and seawalls.

Responses to Shoreline Change

Armoring

Shore-parallel, back-beach armoring provides no benefit to beaches; however, these structures provide protection to the shoreline and adjacent structures. Over 10 percent of California’s 1,100 miles of coast have been armored to date (Griggs 2010; PPIC 2008). The State allows armoring when required to serve coastal-dependent uses, protect existing structures in danger from erosion of cliffs or bluffs, and when designed to mitigate impacts on shoreline sand supplies (CCA, §30235). Nevertheless, public beachgoers and environmental interest groups have expressed a preference for soft alternatives despite state policy exceptions that allow hardened structures if they are found to be the least environmentally-damaging alternative. The general view has been that environmental and recreational interest groups generally oppose shore-parallel armoring because it negatively affects the beach environment and beachgoers’ experience by blocking or limiting public access, increasing erosion along the adjacent shoreline, reducing beach width, and having a negative impact on aesthetic values (Griggs 1998, 2010; Stamski 2005). A recent study in Santa Barbara and Ventura Counties found that seawalls, revetments, and groins have neither a negative nor positive effect on the beach experience (Sterrett 2013). One 2008 study estimated that the
total sediment lost from the California shoreline because of seawalls and revetments is approximately 50,000 cubic yards per year (Magoon and Treadwell 2008). Patsch and Griggs (2006) did the original calculations on these losses and computed 43,000 cubic yards per year lost from armoring for the entire State and 35,000 cubic yards per year for Southern California.

**Costs of Armoring**

Armoring can be quite costly (Table 14). Heberger’s estimate of $5,300 per foot in Table 14 represents estimates from California, Philadelphia, and New England. Heberger found costs ranging from $3,800 in Southern California to $6,200 in Northern California (Heberger et al. 2009).

**Table 14. Estimates of costs of armoring (construction only).**

<table>
<thead>
<tr>
<th>Study</th>
<th>Riprap (linear ft)</th>
<th>Seawall (linear ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public Policy Institute of California (PPIC) 2008</td>
<td>$750</td>
<td>$10,000*</td>
</tr>
<tr>
<td>CA Coastal Commission 1999</td>
<td>$1,000–2,000</td>
<td>$1,000–5,000</td>
</tr>
<tr>
<td>Griggs 1992</td>
<td>$500–1,000</td>
<td>n/a</td>
</tr>
<tr>
<td>Griggs 2005a</td>
<td>n/a</td>
<td>$1,800–7,600</td>
</tr>
<tr>
<td>Griggs 2005b</td>
<td>n/a</td>
<td>$1,000–7,500</td>
</tr>
<tr>
<td>Heberger et al. 2009 (Pacific Institute)</td>
<td>n/a</td>
<td>$5,300</td>
</tr>
</tbody>
</table>

*combined with bluff reconstruction and retaining walls

The total expenditures on hardened structures along California’s coast are difficult to determine because of a variety of factors, including information availability and calculating projected maintenance costs. Generally, the ratio of maintenance costs to construction costs for armoring projects varies, depending on the level of engineering; the greater the engineering, the lower the proportion of maintenance cost. Heberger et al. (2009) estimated that maintenance of an engineered revetment could amount to 2 to 4 percent of the construction cost per year over the life of the project as compared to a non-engineered revetment, for which maintenance can cost 5 to 15 percent of the construction cost per year. The estimated maintenance cost for highly-engineered seawalls ranges from 1 to 4 percent per year (Heberger et al. 2009).
Nourishment

Nourishment is the preferred soft strategy for addressing erosion of public beaches in situations where restoration of the shoreline is deemed necessary (California Coastal Commission 1999; DBW and State Coastal Conservancy 2002; Grove 2007). Nourishment for maintaining beaches is most common along the Southern California shoreline, which has undergone more alterations to the natural system (e.g., dams, flood control, armoring) than the other regions (CA DBW 2002) and is more densely populated. A key finding of Griggs et al. (2005) is that over the twentieth century, large-scale construction projects along the coast provided enough artificial sand to keep up with sediment losses from dams and other sediment traps. Those types of major construction and development projects are no longer happening.

While nourishment may appear to be an attractive alternative to coastal armoring or retreat, there are a number of issues to be considered and addressed. These include the source and method of obtaining appropriate sand, costs and impacts of removing and transporting large volumes of sand to the site, financial responsibility for the initial project and subsequent re-nourishment, the potential impacts of sand placement, and the lifespan of the nourished sand. Because of the high littoral drift rates that characterize most of the California coast, sand added to a narrow beach cannot be expected to remain at that location for any extended period of time. Sand retention systems have been used effectively at a number of sites in California as a way to significantly extend the lifespan of a beach nourishment project (Griggs et al. 2006).

For example, beach nourishment at Surfside-Sunset began in the 1960s and is conducted every 4 to 6 years, with stage 14 coming in about 2017 (Figure 23 and Figure 24).

There are limited funding sources available for beach nourishment projects in the State, other than project sponsors. Section 204 of the Water Resources Development Act (2007) authorizes implementation of projects for the protection, restoration, and creation of aquatic and ecologically related habitats, including wetlands, in connection with dredging for construction, operation, or maintenance of an authorized navigation project. While $5 million is authorized nationally for these purposes, these funds are quite limited in their use, and such projects have to go through USACE’s project feasibility and development process. NOAA’s Monterey Bay National Marine Sanctuary occasionally receives settlement funds from enforcement actions against violations involving disturbance of the Sanctuary seabed. These funds must be used to protect and restore Sanctuary habitats, which may include beach projects. In terms of state funding sources, the California Division of Boating and Waterways is responsible for allocating funds for beach restoration projects via the Public Beach Restoration Act’s Public Beach Restoration Program. In some cases, state money from this program has been used to...
leverage federal funding. The program is allowed to fund 100 percent of project construction costs for beach nourishment at state beaches, and a maximum of 85 percent of costs for projects at non-state beaches. Local municipalities are required to provide a 15 percent match of costs for these projects (California Public Beach Restoration Act, Section 69.5–69.9). In addition, the California Coastal Conservancy (a state agency) is able to purchase, protect, restore, and enhance coastal resources, as well as provide access to the shoreline. Finally, the California Coastal Commission is another potential source of funding via the fees it collects through the Coastal Development Permit process. Money from this fund is used to implement public recreational improvement projects.

**Costs of Nourishment:**

Since 1984, the Los Angeles and San Francisco Districts of USACE, State of California, and local interests have undertaken eleven nourishment projects to restore beach widths on popular public beaches (Table 15). Between 1984 and 2012, the state and federal government together spent $93.5 million to place 13.4 million cubic yards of sand on Southern California beaches. Surfside Beach in Orange County received 71 percent of this sand (9.6 million cubic yards).

**Table 15. Beach Nourishment Projects from 1984 to Present (2013) for California.**

*Source: USACE, Los Angeles and San Francisco Districts, and California Division of Boating and Waterways*

<table>
<thead>
<tr>
<th>Project &amp; Location</th>
<th>Year</th>
<th>Federal</th>
<th>State</th>
<th>Region / Local</th>
<th>Combined</th>
<th>Volume yards³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surfside-Sunset, Orange Co</td>
<td>1984</td>
<td>$3,690,000</td>
<td>$1,539,000</td>
<td></td>
<td>$5,229,000</td>
<td>2,380,000</td>
</tr>
<tr>
<td>Surfside-Sunset, Orange Co</td>
<td>1990</td>
<td>$5,363,000</td>
<td>$2,616,000</td>
<td></td>
<td>$7,980,000</td>
<td>1,820,000</td>
</tr>
<tr>
<td>Seal Beach</td>
<td>1999</td>
<td></td>
<td>$813,000</td>
<td></td>
<td>$813,000</td>
<td>95,000</td>
</tr>
<tr>
<td>Goleta Beach</td>
<td>2001</td>
<td></td>
<td>$1,750,000</td>
<td></td>
<td>$1,750,000</td>
<td>61,000</td>
</tr>
<tr>
<td>SANDAG RBSP 1</td>
<td>2001</td>
<td>$12,000,000*</td>
<td>$6,023,000</td>
<td></td>
<td>$18,023,000</td>
<td>2,100,000</td>
</tr>
<tr>
<td>Surfside-Sunset, Orange Co</td>
<td>1997</td>
<td>$6,491,000</td>
<td>$3,147,000</td>
<td></td>
<td>$9,638,000</td>
<td>1,630,000</td>
</tr>
<tr>
<td>Surfside-Sunset, Orange Co</td>
<td>2002</td>
<td>$5,482,000</td>
<td>$2,649,000</td>
<td></td>
<td>$8,130,000</td>
<td>2,233,000</td>
</tr>
<tr>
<td>San Clemente</td>
<td>2007</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5,000</td>
</tr>
<tr>
<td>Seal Beach</td>
<td>2009</td>
<td></td>
<td></td>
<td>$1,000,000</td>
<td></td>
<td>100,000</td>
</tr>
<tr>
<td>Surfside-Sunset, Orange Co</td>
<td>2009</td>
<td>$10,239,000</td>
<td>$4,444,000</td>
<td></td>
<td>$14,682,000</td>
<td>1,500,000</td>
</tr>
<tr>
<td>SANDAG RBSP 2</td>
<td>2012</td>
<td>$17,900,000</td>
<td>$8,300,000</td>
<td>$8,300,000</td>
<td>$26,200,000</td>
<td>1,500,000</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td></td>
<td>$43,265,000</td>
<td>$40,881,000</td>
<td>$9,300,000</td>
<td>$93,446,000</td>
<td>13,424,000</td>
</tr>
</tbody>
</table>
Several studies have attempted to predict the economic impacts of nourishing or not nourishing beaches in California. As noted earlier in this section, one study modeling recreational benefits related to beach width at San Clemente city and state beaches predicted that a 50-percent increase in beach width can generate $3.1 million in consumer surplus per year (Pendleton et al. 2011). One survey administered in Southern California found that beach width is important to beach users; at one beach in San Diego it was estimated that loss of beach width could result in a loss of $300 million in revenue (King 2001). In a study on beach recreation value, Lew and Larson (2004) estimated that along San Diego beaches, a loss of $4.25 (or 15 percent) from a single beach trip value of $28.27 per person could be attributed to the presence of cobble stoning because of erosion and lack of beach sand. An analysis (Pendleton et al. 2009) examining the potential economic effects of sea level rise in Southern California estimated substantial loss for the region (between $40 million and almost $63 million annually), indicating that the current federal costs of nourishment are an overall positive economic driver.

Retreat

Managed retreat is a response to erosion involving abandonment or relocation of threatened structures or infrastructure away from the eroding shoreline. California has primarily used retreat to address erosion on public land. Two case studies in this report (Surfer’s Point and Stilwell Hall) are examples of this practice. Retreat is a less common option for private homeowners, who tend to rely heavily on armoring and other strategies to protect their investment. The dense development along the California coast leaves few options for homeowners who may desire to proactively move their homes back from the shore. The presence of cliffs or bluffs may also affect opportunities for retreat. There are many cases in California of bluff-top construction where buildings have been relocated or lost, and this will become increasingly more likely as erosion progresses with sea level rise (Figure 25 and Figure 26). The city of Pacifica is an example of a municipality that, in partnership with a non-profit organization and the California Coastal Conservancy, purchased two homes and surrounding land that was vulnerable to flooding. The homes were purchased for $2.2 million, demolished, and 4,000 cubic yards of sand were brought in to rebuild dunes and restore the beach (NOAA 2007).

Figure 25. Stilwell Hall in 2004 in southern Monterey Bay at Fort Ord. 
Note the attempt to control bluff erosion with rip-rap. Source: California Coastal Records Website
Beach Recreation: Surfing

Within the past decade, several studies and reports on recreational beach uses and the value of beaches have been published in California. These reports were produced for the Department of Boating and Waterways to evaluate whether state and federal funding for beach nourishment projects could be justified for municipalities in Southern California (King 2001a, 2001b, 2001c and 2006). These studies, in conjunction with the National Ocean Policy established in 2010, have showcased the importance of data collection on non-consumptive beach uses like surfing.

A survey conducted by NOAA over a decade ago indicated that 3.3 million people surfed in the U.S., and one-third of those surfers resided in California (Figure 27). The warm weather and water temperatures make Southern California a year-round international surfing destination and the birthplace of the American surfing culture, but surfers and their use of the coastal zone have only recently become the focus of recreational surveys and studies. For years, attempts at valuing the recreational uses of beaches never distinguished between surfers and other recreational beach users. Traditional quantitative survey methods, such as mail surveys, have not been cost-efficient in capturing less common recreational uses practiced by small segments of the population (e.g., surfing, spear fishing, paddle boarding). Qualitative studies of surfers, which do not tend to rely on large and representative samples, would likely provide useful data, but are not commonly seen in the literature.
A 2011 report compiled by Surf-First and the Surfrider Foundation (Wagner et al. 2011) established the first national characterization of surfers, including assessments of their economic contributions to specific locations. The report, based on Internet opt-in survey results, was able to extract mean expenditures of surfers per visit for six regions in Central and Southern California (Table 16). The expenditure per visit data in Table 16 are notably surprising, not necessarily corresponding to seemingly normal patterns of surfers going to the beach with “snacks and boards” and not stopping at local stores. The data are from actual experiences by surfers that responded to the opt-in survey.

Table 16. California regional recreation and expenditures for surfers.

<table>
<thead>
<tr>
<th>Region</th>
<th>Arrival Time</th>
<th>Duration (hours)</th>
<th>Distance Traveled (one way)</th>
<th>Visits per year</th>
<th>Expenditure per visit (mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Los Angeles County</td>
<td>8:00AM</td>
<td>2:00</td>
<td>9.5 miles</td>
<td>108</td>
<td>$54</td>
</tr>
<tr>
<td>Orange County</td>
<td>7:30AM</td>
<td>2:30</td>
<td>10 miles</td>
<td>124</td>
<td>$58</td>
</tr>
<tr>
<td>San Francisco Bay Area</td>
<td>9:15AM</td>
<td>2:00</td>
<td>15 miles</td>
<td>95</td>
<td>$66</td>
</tr>
<tr>
<td>San Diego County</td>
<td>8:15AM</td>
<td>2:00</td>
<td>5 miles</td>
<td>144</td>
<td>$58</td>
</tr>
<tr>
<td>Santa Cruz County</td>
<td>8:45AM</td>
<td>2:30</td>
<td>10 miles</td>
<td>81.5</td>
<td>$70</td>
</tr>
<tr>
<td>Ventura County</td>
<td>8:30AM</td>
<td>2:30</td>
<td>7.5 miles</td>
<td>144</td>
<td>n/a</td>
</tr>
</tbody>
</table>

*Bonferroni, Scheffe, and/or Sidak multiple comparison tests indicate the mean of the sample is significantly different from at least one other at the .05 significance level or greater.

Note: All figures are medians unless noted. N/A denotes insufficient number of responses

The recognition of surfers’ distinct beach use patterns, their impact on the local economies around popular surf spots, and the success of their main advocacy group, the Surfrider Foundation, have contributed to the growing influence of their interests in coastal issues. The Surfer’s Point Retreat Project is one example where
the influence of surfers’ interests in combination with the project’s location on public land led to the choice of managed retreat over hardened structures (see case study). Armoring in response to coastal erosion presents some unique problems for surfers as compared to other beachgoers because surfers depend more on the conditions of the waves rather than the dry beach area. One survey-based study (Corne 2007), which included California surf spots, found that wave quality was reduced after coastal armoring was installed. However, the same study found improvements in surf experiences in Oregon because of jetties. Jetties have been used along the California coast for over 50 years to stabilize river mouths and harbor entrances (the jetty at Humboldt Bay was built in 1888). Although shore-parallel hardened structures may negatively interfere with surfers’ and other beach recreational users’ experience, shore-perpendicular structures, such as jetties and groins, may enhance surfers’ experiences. In several Southern California locations, these hardened structures are thought to have created or enhanced surfers’ experiences (e.g., Huntington Beach and Newport Beach).

**Challenges Quantifying Economic Effects of Shoreline Change**

**Recreational Value**

The importance of beach recreation and tourism to the State’s economy is often used to justify the cost of coastal storm damage reduction projects. Approximately 70 percent of California residents visit the coast once per year, and the majority of them believe that the ocean and beaches are very important to the State’s economy (Pendleton and LaFranchi 2009; Public Policy Institute of California 2003). Beyond the opinions of Californians, several studies have estimated the value of California’s beaches to both the State and the country. The California Department of Boating and Waterways estimated that visitors to California’s beaches spent $61 billion in 2001 (CA DBW 2002). Kildow and Colgan (2005) estimated that 86 percent, or $42.9 billion of the gross state product in 2000 came from the coastal counties. Recently, sea level rise (and associated potential increases in erosion rates) has been gaining attention in the State as a threat to the State’s fiscal stability (du Vair et al. 2003; Hanak and Moreno 2008; PPIC 2008; Tribbia and Moser 2008; California Natural Resources Agency 2009; Heberger et al. 2009; The Pacific Institute 2010).

Despite the comparatively rich literature on the economic value of the California coast, data quantifying the value of recreational activities occurring on beaches are spotty. There has been a growing emphasis on determining the non-market value of beach recreation since the 1990 American Trader case, in which the value of lost recreational beach use because of oil pollution had to be determined to properly assess damages (Chapman and Hanemann 2001). From this case and several studies since then (King 2001a, 2001b; Lew and Larson 2004, 2008; Hanemann et al. 2005; Pendleton and Kildow 2006; Nelsen et al. 2007; LaFranchi and Pendleton 2009; Pendleton et al. 2011), it is clear that, despite the many challenges in collecting data on recreational beach uses, cities, counties, and the State recognize the importance of understanding the value of beaches.
**Expenditure Data**

The State of California has been managing sediment along its coast for more than a century. Despite the long history of dredging and nourishment activities, tracking and gathering basic information on these projects remains a challenge. There are several systems within the State and in USACE where information on armoring, nourishment, and other coastal shoreline and sediment-related projects can be accessed by the public or shared across state and federal agencies. The USACE Operations and Maintenance Business Information Link (OMBIL) is one potential source of expenditure information for beach nourishment and dredging projects. Los Angeles and San Francisco District personnel provided data on expenditures and volumes of dredged material included in this report (Appendix C). California Department of Boating and Waterways staff provided state nourishment expenditures.

While it is helpful to have estimates on the value to recreational users of a quality beach (or conversely, the losses in value associated with shoreline erosion), these estimates alone are not sufficient to determine economic impacts. As federal, state, regional, and county governments continue to spend millions of dollars annually on sediment management projects, one possible approach would be to consider developing and implementing a centralized system where all projects can be tracked. Considering the multitude of agencies and levels of government, this approach is noted to be difficult to implement. Government authorities, however, would then be able to comprehensively assess current expenditures to address shoreline change and, from such assessment, gain a more accurate accounting of costs and a better understanding of the economic impacts of eroding and accreting shorelines.

In tracking sediment management projects, and in particular beach nourishment projects, assessment of the actual economic impact needs to take into account federal, state, and local expenditures and the expected frequency for nourishment over the long term, given climate change and increases in storminess. For example, SANDAG 1 (Torrey Pines) in Table 15 lost much of the placed sand during one storm, and most of the placed sand was gone within two years. One factor thought to be a contributor in that rapid loss was that the quality of the placed material was not totally compatible with the local conditions.

**Summary of Gaps in Research and New Approaches**

Although this report has assembled information that can contribute to the understanding of the economic and social impacts of erosion, these impacts are not completely captured by examining only the federal and state expenditures on beach nourishment and the estimated costs of armoring. This report acknowledges there were several obstacles when attempting to calculate the total costs of erosion and accretion including:

- Private property owner expenditures on seawalls, nourishment (and mitigation fees), and structural repairs are not documented;
- Port and harbor expenditures on dredging have to be individually extracted from maintenance and operational budgets;
- Local and regional spending on armoring or nourishment have to be individually extracted from town, city, or county budget reports; and
- For the most part, costs of lost recreational opportunities because of erosion are difficult to isolate from estimated values of beach visits.
Additionally, several gaps in information were identified:

- Centralized dataset on nourishment projects and costs (including local and county efforts).
- Centralized database that tracks permits granted for hard structures to protect private property.
- Non-consumptive beach use data and associated economic information, especially for less-common activities (e.g., surfing, paddle boarding,) (Grove 2007; LaFranchi and Pendleton 2009).
- How to account for the costs associated with opportunistic nourishment (projects that place dredged material from navigation projects on adjacent beaches), and the extent to which such expenditures can be considered a cost of erosion and accretion.
- Studies comparing costs of different strategies to manage erosion and accretion.

Box 13 summarizes the Coastal Sediment Benefits Analysis Tool developed by the USACE, State of California, and local agencies, to support preparation of sediment management plans. The tool also addresses a number of the gaps in knowledge identified above.

**Box 13. Coastal Sediment Benefits Analysis Tool**

In support of Regional Sediment Management plans, USACE, the State of California, and other local agencies collaborated to create the Coastal Sediment Benefits Analysis Tool, which is a GIS-based tool that conducts cost-benefit analysis for various beach nourishment alternatives explored within Regional Sediment Management (RSM) plans. Manipulating different components creates scenarios and alternatives: sediment-source location, receiver-site location, transportation modes, recreational usage, and environmental considerations (Poon et al. 2008). The calculation of benefits, which is based on potential changes in recreational value of the beach, is derived from a variety of inputs, including an assumption that doubling beach width will increase attendance by 2.5 percent and recreational value (per visitor) by 18 percent (this is derived from King 2001). The other inputs into the Coastal Sediment Benefits Analysis Tool underscore the importance of the role of the State and communities in collecting and updating beach recreational use and value data (e.g., maximum value of beach day visit per person, beach attendance counts, non-California beach visitors) (AMBAG 2008).

The Coastal Sediment Benefits Analysis Tool produces reports containing information such as baseline data on the nourishment sites, estimated beach nourishment costs, change in recreational benefits, projected increases in spending and tax value, potential environmental impacts, estimated change in beach width, and cumulative costs and benefits using various transportation routes and scenarios (AMBAG 2008). The Coastal Sediment Benefits Analysis Tool will continue to be valuable to regional organizations in the development of RSM plans because it allows the end user to accomplish two tasks in an efficient and effective manner: 1) determine the least-cost method of transporting sediment and 2) determine the volume of sediment that provides the greatest increase in recreational value (Poon et al. 2008).
5. ENVIRONMENTAL EFFECTS OF EROSION AND ACCRETION

California Coastal Environment

The California coastal environment contains diverse habitats, including wetlands, estuaries, kelp forests, sea-grass beds, mudflats, bluffs, cliffs, sandy beaches, and dunes. These areas provide important habitat to a variety of plant and animal life. At the same time, increasing pressure on coastal areas from human activity (e.g., development, fishing, and recreation) is having profound impacts on the natural cycles of sand and sediment distribution in the coastal habitats (U.S. Commission on Ocean Policy 2004). According to Dahl (1990), human activities in California have reduced coastal wetlands by 91 percent since the 1780s. Human activities also have disturbed shallow reefs near urban coasts and seagrass beds (U.S. Commission on Ocean Policy 2004).

Sediment flow in coastal areas is a complex process that interacts with the physical environment, marine life, and human communities along the coast. Coastal sediment is in a constant state of flux because of natural forces from wind and waves—these forces continually build up and wear away coastal land features, such as beaches, dunes, inlets, and vegetated coastal environments. This results in a variety of seasonal conditions with associated changes in ecological communities.

The objective of this section, “Environmental Effects of Erosion and Accretion,” is to briefly describe the environmental effects of erosion and accretion. The effects are described but they are not quantified, nor could they, given the dynamic and complex conditions along the coastline and the associated habitat and biological resources. Appendix D provides a description of the coastline landforms and habitats and their associated biological resources. A specific description of the landforms and biological resources is then provided for the Northern Coastal Region, Central Coastal Region, and Southern Coastal Region.

Description of Environmental Effects of Erosion and Accretion

In terms of coastal management, sediment can have both beneficial and undesirable impacts. Sediment is an important resource to create or restore beaches and other coastal habitats. Whether sediment is abundant or in minimal supply, coastal habitats and ecosystems will be affected by the constantly changing coastal environment.

- Too much sediment can damage habitats, interfere with the food chain, and cause obstructed channels, overflowing rivers, smothered reefs, and high turbidity that blocks sunlight.
- Too little sediment can lead to disappearing beaches and other eroded coastal features with significant implications for aquatic and terrestrial habitat for a wide variety of species, potentially reducing the abundance and biodiversity of such animals as fish, turtles, and birds.

Effects on Beach and Shoreline Habitats. Erosion of dunes and beaches occurs when factors interrupt the natural supply of sediment disproportionately in relation to sand transported onto or off the dunes or beach. Rising sea levels and human activities are a growing cause of permanent erosion on beaches and dunes (Dahm, Jinks and Bergin 2005). Sand dune erosion is a serious concern because these land forms mitigate coastal hazards and protect beaches (Dahm et al. 2005). Dunes and their vegetation play a key role in maintaining the sand balance of the total beach system; dune grasses grow on the windward face and help...
to entrap sand for the dune, serving as reservoirs for the beach. Dunes eroding faster than they can repair themselves negatively affect the maintenance of beaches (providing human recreational opportunities and habitat), protection from coastal hazards like flooding (Dahm et al. 2005), and habitat for a variety of plants and animals that live on the coastal dunes [e.g., succulent plants, grasses, variety of insects, deer mice, California voles, lizards, hawks, foxes, and skunks] (California Coastal Commission 1987). Dunes and beaches offer a range of beneficial ecosystem services, such as habitat to a variety of invertebrates, crustaceans, and birds, and a wide-reaching nutritive structure, mostly from animals that live in the sediment (e.g., bacteria, microalgae, mollusks, and crustaceans).

Beaches and beach habitats, along with bluffs, terraces, and rocky shores, provide a crucial corridor for terrestrial animals and birds to access the water (Shaffer 2002). Fish and birds can forage for invertebrates on beaches and intertidal areas. When beaches and coastal habitats are adversely affected by erosion and accretion, the invertebrate populations that live there are likely to decrease, but they are known to be highly adaptive and mobile in the larval stage. Many invertebrates are able to cope with naturally occurring levels of sedimentation, turbidity, and even burial (Greene 2002; Wilber et al. 2005). Loss of beach nesting habitat is one of many environmental concerns that threaten the California turtle population (California Coastal Commission 2002).

**Box 14. California Grunion**

California grunion (*Leuresthes tenuis*) are a non-migratory species of fish found in an area ranging from the San Francisco Bay to southern Baja California. Grunion live in kelp beds up to a depth of 60 ft (20 m) off sandy beaches. During spawning season, which spans from March to August, grunion move closer to shore, just beyond the surf line (SAIC 2012).

When spawning, grunion use breaking waves to swim as far up the beach as possible, where they lay and fertilize their eggs. The eggs are initially buried several inches below the sand, which protects the eggs from the elements and predation. Receding waves add sand, burying eggs to depths of 6 to 8 inches (15 to 20 cm), with some reports of burial depths as high as 18 inches (46 cm).

Gently-sloped beaches are an ideal habitat for spawning, as oxygen availability is a key to egg survival. Grunion generally do not spawn on steep beaches, nor on flat beaches. The latter are not favorable to grunion spawning, as the sand may become saturated with water, and reduce oxygen availability for the eggs. Substrate is also a factor in grunion spawning. Sandy sediment permits more gas exchange than fine sediment, making it more conducive to egg survival.

Beach erosion limits grunion habitat suitability for spawning and can reduce the length of the spawning season. Consequently, beach nourishment (accretion) activities may benefit grunion by increasing spawning habitat and lengthening the spawning season. However, beach nourishment activities can also damage spawning habitat by burying eggs too deep, or dislodging or crushing the eggs with vehicles and other equipment. Mitigation strategies include single-point disposal and re-directing beach nourishment activities away from spawning areas.

Grunion are listed as a species of concern by the California Department of Fish and Game (CDFG). As a result, certain activities are restricted to protect grunion populations. Limited recreational fishing of grunion is permitted during the month of March, followed by June through August. Fishermen must capture grunion by hand, without equipment. Additionally, beach nourishment activities are restricted to outside of spawning season to minimize impacts (SAIC 2012).
Because marine mammals are near the top of the marine food chain, the erosion and accretion related losses of their food (e.g., invertebrates and fish) will affect individuals and populations. Further, “haul-out” sites are important to pinniped species. Hauling-out is when the animal temporarily leaves the water between periods of foraging activity. Hauling-out is necessary for seals to mate and give birth (at rookeries) and is also important for predator avoidance, thermal regulation, social activity, parasite reduction, and rest (Daugherty 1985). When erosion and other causes disturb breeding sites of marine mammals, there are impacts to the population. Erosion and associated loss of habitat can simply mean that there are not enough sites for breeding and colony space. In addition, there could be increased exposure to predation. Another impact of reduced habitat from erosion is that there would be fewer areas to rest for energetic and thermoregulatory purposes (Robinette et al. 2009).

**Effects upon Wetlands and Salt Marshes.** The effects of erosion upon wetlands and salt marshes can be positive or negative depending upon the local topography and the need for sediments to maintain the balance. Wetlands and salt marshes can be quite resilient and adapt to changing conditions. Wetlands and salt water marshes provide an array of ecosystem services contributing to the economy and social well-being. Commercial and sports fisheries along the coast depend upon wetlands to serve as the nursery for spawning, foraging, and cover for small fish as they grow. Birds, like fish, depend upon wetlands for migratory resting places, breeding and feeding grounds, and cover from predators. Wetlands serve as filters for nutrients and sediments, helping to control issues of sedimentation, eutrophication, and water quality problems in bays and coastal waters. Other well-known functions of wetlands that can be impacted by erosion and accretion include:

- Flood mitigation: Wetlands temporarily store floodwaters, releasing them slowly into the system reducing flood peaks and surges;
- Recreational opportunities, including fishing and hunting;
- Potential for educational opportunities, serving as outdoor classrooms;
- The beauty and opportunities to experience nature; and
- Enhancing the value of adjacent properties.

For both resident and migratory sea birds, habitat and associated food loss would adversely affect these populations. Migratory birds would experience hardships from food loss. Nesting colonies can be harmed by erosion and associated habitat loss (Sowls et al. 1980). Hubbard and Dugan (2003) note the direct relationship between accumulated sand on beaches and available habitat for shorebirds. Reductions in sediment supply, because of anthropogenic disturbances (e.g., dams and hardened structures), can reduce this habitat and available food.

**Effects of Turbidity and Sedimentation.** Erosion and accretion are associated with elevated levels of suspended sediment in the water and an increased amount of sediment settling on the seafloor.

Excessive turbidity, caused by fine-grained sediments and colloidal materials, degrades water quality and increases morbidity among marine life (Berry et al. 2003). Higher turbidity increase water temperatures as suspended particles absorb heat, as well as reduce the concentration of dissolved oxygen. Increased turbidity also reduces the amount of light penetrating the water, which reduces photosynthesis (Berry et al. 2003).
2003) and can have harmful impacts on estuaries, wetlands, kelp forests, eelgrass, and surfgrass. For example, eelgrass requires significant sunlight and even small changes in light access can substantially affect eelgrass habitat (California Department of Fish and Game 2008).

High levels of suspended and bedded sediment can negatively affect invertebrates (Berry et al. 2003; Greene 2002) through abrasion, “clogging of filtration mechanisms thereby interfering with ingestion and respiration, and in extreme cases smothering and burial resulting in mortality” (Berry et al. 2003). Increased sedimentation also can affect photosynthesis and harm plant food sources. Suspended materials can clog fish gills, reduce resistance to disease in fish, lower growth rates, and affect egg and larval development (Berry et al. 2003; Germano 2005).

Increased sedimentation can blanket the sea floor and smother fish eggs (Berry et al. 2003). The most sensitive fish resources are the eggs of benthic fish that are unable to attach, grow, or hatch because of sedimentation (Berry et al. 2003; Wilber et al. 2005). Adult benthic fish can have strong attraction to certain substrate types but are also capable of relocating. However, relocation may subject fish to increased predation or loss of foraging area (Germano 2005). When particles settle they can smother bottom-dwelling benthic invertebrates (Berry et al. 2003). Non-burrowing substrate organisms, submerged aquatic vegetation, and shell reefs (oysters) may be hardy enough to withstand sedimentation, but if they are impaired, the recovery time is long and populations are difficult to re-establish (Germano 2005). Pelagic fish eggs and juvenile fish could be affected because they settle on the bottom where sedimentation would affect them.

Among the impacts, sudden increases in sediment in the water column can impede migratory paths for anadromous fish, such as salmon (California Coastal Commission 1987). Clarke and Wilber (2000) reviewed available data on the impacts of suspended sediments to fish and shellfish and found that the duration of exposure was a critical aspect in determining mortality of eggs and juvenile fish species. Unexpected sedimentation could cause adult fish to avoid the area and fail to spawn, which could affect population numbers if an alternate site is not found.

Berry et al. (2003) describe a number of studies where birds avoided waters with increased turbidity, expressing a preference for clearer waters. Decreased water clarity might influence bird species to abandon forage or nesting areas.

Summary Note. Erosion and accretion are natural processes, have been ongoing for years, and can provide benefits for beach, dune, and marsh nourishment. Or, they can have negative effects on fisheries and other wildlife through direct impacts, disappearance of habitat, and damage to primary food sources. Coastal managers need to consider human-induced changes to the natural erosion and accretion cycles that adversely impact habitats, and fish and wildlife populations.
Sediment Management and the Environment

Lessons learned from past and current coastal erosion management efforts can guide future decisions. As described in the previous section, beach nourishment, or replenishment, is one management tool to address coastal erosion by replacing lost sediment or sand with material from sources outside of the eroding beach (Hapke et al. 2006; Appendix C in this report). This activity stems erosion, enhances beach recreation opportunities, and improves habitat (Kalo 1990). As presented in Box 15, there can be unintended negative environmental consequences from beach nourishment, including: short-term disturbance of the indigenous biota of the beach (e.g., by smothering with new sand or with incompatible material); impacts to the food web (e.g., potential to alter habitats or adjacent areas used by species for nesting, nursing, and breeding); environmental impacts in the subtidal area, such as increased turbidity; and impacts to the biota in the sand borrow area (NRC 1995). Turbidity effects in the subtidal area can include negative impacts on sea bottom vegetation from light reduction, interference with foraging or migration of sensitive species from reduced water clarity, or sublethal (e.g., larval growth, feeding) or lethal stress to fishes or invertebrates.

Placement of sand on a beach results in a temporary reduction in the invertebrate forage base for fish and shorebirds. The recovery is generally in a year or less, especially when sand is placed on sand-starved beaches with limited habitat functions. California grunion may use the new beaches and habitat right away for spawning and birds can use it for resting. Benthic recovery rates at offshore borrow sites mostly range from 1 to 3 years.

Box 15. Types of Impacts from Sediment Management Activities

Direct
- Equipment damage to habitats (e.g., anchors, pipelines, vehicles), and injury of species
- Discharge burial of habitat and invertebrates
- Dredge removal of habitat and invertebrates
- Dredge entrainment of invertebrates and fish

Indirect
- Invertebrate forage reduction
- Disturbance or interference (e.g., noise, lights, equipment) of wildlife movement or migration
- Turbidity effects (reduced photosynthesis, feeding, growth, or mortality)
- Sedimentation effects (reduced photosynthesis, recruitment, nutrient stimulation, or mortality)
- Enhanced sandy beach habitat and supported bioresources

Source: Extracted from SAIC 2012

Impacts to water quality, turbidity effects on plants and animals, sedimentation associated with settlement of the suspended sediments are similar for both placement of the sand on the beach and for
dredging at the borrow site, or in the navigation channel if that is the source of sand. Turbidity and sedimentation usually dissipate rapidly after dredging and placement are completed. Over relatively short periods, many marine species are able to adapt with increased levels of turbidity and suspended sediments, similar to natural events caused by storms. Long-term exposures can be problematic to fish and benthos.

While the potential adverse impacts of beach nourishment are acknowledged in Box 15, the judgments by government authorities are usually that the benefits outweigh the negative impacts. Examples of positive impacts of beach nourishment upon the biological resources are shown in Table 17.

**Table 17. Examples of biological benefits from beach nourishment projects.**
*Source: Extracted from SAIC 2012*

<table>
<thead>
<tr>
<th>Biological Resource Benefit</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Erosion Protection</strong></td>
<td></td>
</tr>
<tr>
<td>Endangered plants</td>
<td>Boca Raton, Florida</td>
</tr>
<tr>
<td>Vegetated foredunes</td>
<td>New Jersey</td>
</tr>
<tr>
<td>Bown pelican nesting habitat</td>
<td>Bird Key, South Carolina</td>
</tr>
<tr>
<td><strong>Enhanced Nesting and/or Spawning Habitat</strong></td>
<td></td>
</tr>
<tr>
<td>Piping plovers</td>
<td>Maryland, Massachusetts, New Jersey, and New York</td>
</tr>
<tr>
<td>Snowy plovers</td>
<td>San Diego, California</td>
</tr>
<tr>
<td>California grunion</td>
<td>San Diego, California</td>
</tr>
<tr>
<td><strong>Enhanced Resting Habitat</strong></td>
<td></td>
</tr>
<tr>
<td>Shorebirds, gulls, terns</td>
<td>North Carolina, and San Diego, California</td>
</tr>
<tr>
<td><strong>Enhanced Nutritive Value</strong></td>
<td></td>
</tr>
<tr>
<td>Early season development-intertidal invertebrate community</td>
<td>San Diego, California</td>
</tr>
<tr>
<td>Increased bird foraging opportunity across tide conditions</td>
<td>San Diego, California</td>
</tr>
</tbody>
</table>

*Figure 29. Beach nourishment project in Carlsbad, CA. (Credit: SANDAG)*
6. CALIFORNIA’S SYSTEMATIC APPROACH TO COASTAL EROSION AND SEDIMENT MANAGEMENT

With the formation of the California Sediments Management Workgroup (CSMW) in 1999, California began systematically addressing erosion issues and managing sediments along the entire reach of the State’s coastline. Prior to that, the traditional approach was funding and managing erosion and sediment management projects individually without careful consideration of potential trade-offs between projects. Coastal erosion and accretion, impacts of sea level rise, loss of valuable property, existing and future economic losses because of fewer recreational opportunities, loss of habitat, and impacts on marine and terrestrial species are a few of the drivers that led a coalition of federal, state, and local agencies and other stakeholders to create the CSMW. The CSMW’s mission is to institute a systematic approach that considers sediment as a resource, identifies sediment sources and sinks, and finds the best and most cost-effective uses of sediment across project lines and political boundaries.

As presented earlier in this report, California’s problems related to erosion and accretion are due to natural and anthropogenic activities. Dams block transport of sediment to the coast, impervious developed areas reduce the availability of natural sediments, dredged channels effectively create sediment traps, mining for sand reduces its availability, and hard structures (e.g., groins, breakwaters, and armoring) influence the availability of sediment. In addition, increasingly-common severe storms with higher wave energy combined with sea level rise challenge existing knowledge and approaches. The traditional approach of site-by-site, project-by-project planning conveniently addresses pressures to take action, mandated authorities, and jurisdictional limitations. Yet, this approach often results in agencies and stakeholders recommending and undertaking actions that may be cost-effective in the short term, but ignore longer-term shoreline and sediment resource management considerations. Understanding these dynamics and working with the existing regulatory and budgetary processes is the task being undertaken in California.

Using a systematic approach that takes a holistic view of sediment imbalances is a hard task. Legislative and regulatory procedures, policies, and budgetary processes must be addressed to change traditional ways of managing shorelines and sediments. The CSMW and a number of local collaborations are leading the State’s efforts to change the focus to broader concepts of sediment management (Box 16; Figure 30).
Box 16. Principles of Systematic Sediment Management*

1. Establish the regional framework (i.e., littoral cell boundaries, sediment budgets, and regional regulatory jurisdiction).
2. Examine the human activities that have affected coastal sediment supply and transport.
3. Develop priority areas within each region for implementation activities.
4. Identify opportunities to restore sediment balance throughout the affected region through modifications to the sediment transport processes.
5. Determine issues that may inhibit implementation of these opportunities (e.g., funding, regulatory process, and existing or lacking national policies).
6. Develop tools to address these issues in an environmentally responsible manner.
7. Obtain funds to pay for the incremental costs associated with implementing sediment management.
8. Recognize the need to use non-traditional sources of sediment to help reestablish wide beach areas.
9. Educate concerned stakeholders on the value of sediment and need for regional sediment management solutions.
10. Promote cooperative and coordinated efforts by agencies involved in protection of California’s priceless coastal resources.

*Identified by the California Coastal Sediment Workgroup

Figure 30. The schematic demonstrates how sediment balances can be handled at a system scale.
Using dredged material from navigation projects as a resource instead of disposing it as a waste is one example of systematic sediment management. Beneficial use of dredged material is not a new concept and has been successful in a large number of projects. The idea of a systematic approach is to look at the entire littoral cell and identify opportunities where dredged material can address a problem caused by erosion. The benefits can be economic, social, and environmental. Instead of dumping dredged material from a navigation channel at an offshore disposal site, sediments can instead nourish an eroding beach by placing sand on the beach or in the littoral zone, or sediments can provide materials for a wetland restoration project (CSMW 2009).

**Overcoming the Inertia: Regional Governance and Sediment Management**

To change the sediment-management paradigm takes concentrated efforts of federal, state, and local government interests and the wide range of involved stakeholders. The motivation for taking action is the recognition of the existing and future impacts of erosion and accretion on surfing, bird watching, property loss and associated tax revenues, and irreversible damage to habitats for aquatic and terrestrial species. California has a long shoreline with many different distinct political, economic, and environmental features that challenge the use of a broader and systematic approach to sediment management. Several regional governance organizations have formed over the years to address particular issues at a more manageable scale, which are now deeply involved in systematically addressing issues caused by erosion and accretion:

- The Association of Monterey Bay Area Governments (AMBAG) formed in 1968 for the purpose of regional collaboration and problem solving to address issues related to growth and development. The members’ objectives include shoreline management. The AMBAG region includes Monterey, San Benito, and Santa Cruz County.
- The San Diego Region’s Association of Local Governments (SANDAG) serves as a forum for regional decision-making for the governments of 18 cities and San Diego County. It addresses growth, development, and shoreline management. SANDAG has a Shoreline Preservation Working Group, which adopted a Shoreline Preservation Strategy in 1993 with a focus on beach nourishment (see the SANDAG Case Study).
- The Beach Erosion Authority for Clean Oceans and Nourishment (BEACON) formed in 1992 for the limited purposes of dealing with coastal erosion and beach problems in the cities of Carpinteria, Goleta, Oxnard, Port Hueneme, Ventura, and Santa Barbara, and the counties of Santa Barbara and Ventura (BEACON Website: www.beacon.ca.gov/).

**CSMW: The Systems Approach**

The CSMW (Box 17) is working closely with these and other regional organizations to ensure integration of efforts. One of CSMW’s main goals is to pursue innovative ways to solve coastal sediment imbalance problems along the California coast, often through beneficial use of sand to fortify eroding beaches. The collaborative work of CSMW is important in recognizing the problems of coastal erosion and accretion, including forward thinking and inclusive collaborative approaches to finding solutions.
Box 17. Membership of the CSMW

**State membership:**
- California Natural Resources Agency (CNRA)
- California Department of Parks and Recreation, Division of Boating and Waterways (CDBW)
- California Department of Fish and Wildlife (CDFW)
- California Department of Parks and Recreation (CDPR)
- California Coastal Commission (CCC)
- California Geological Survey (CGS)
- San Francisco Bay Conservation and Development Commission (BCDC)
- State Coastal Conservancy (SCC)
- Department of Fish and Game (CDFG)
- State Water Resources Control Board (SWRCB)
- State Lands Commission (CSLC)

**Federal membership:**
- U.S. Army Corps of Engineers (USACE) South Pacific Division (SPD), Los Angeles District (SPL), and San Francisco District (SPN)
- U.S. Geological Survey (USGS)
- U.S. Environmental Protection Agency (EPA)

CNRA and USACE jointly chair the CSMW, which meets monthly. Figure 31 provides an overview of the CSMW structure, associated partners, teams, workgroups, and actions.
California Coastal Sediment Master Plan

The CSMW determined that the best approach to tackle erosion and sediment issues in a system approach to sediment management along the California coastline would be to develop a Sediment Master Plan for the California coastline. Development of the Sediment Master Plan is expected to be a 10 to 15-year process that identifies information needs, challenges, and actions needed to systematically approach sediment management along the coastline. The Sediment Master Plan is a living document that includes a compilation of tools, outreach actions, strategies, and informational reports designed to assist and guide city and county managers and others in systematically implementing coastal sediment management throughout the California coast. A key part of this effort is a series of regional sediment management (RSM) plans for specific regions of the coastline that determine the best systematic approaches for managing sediment. Collectively, these RSM plans address differences in local issues across coastal California (Figure 32). The CSMW is making significant progress in developing the Sediment Master Plan by adhering to six specific action areas:

1. Increase agency and project coordination;
2. Compile existing information related to coastal sediment management;
3. Make spatial data available through web-based mapping and geographic information system products;
4. Hold public meetings to identify needs and opportunities;
5. Develop governance and technical solutions appropriate for individual regions; and
6. Identify the specific areas to address for more consistent regulations, legislation, and policies.

The CSMW issued the first status report on the Sediment Master Plan in 2006. The most recent update is *The California Coastal Sediment Master Plan, Status Report, June 2012* (CSMW 2012), which is available through the CSMW’s website (www.CDBW.ca.gov/csmw/default.aspx).

**Figure 32.** Sediment Master Plan Development Structure. *Source CSMW Website.*
Accomplishments to Date by CSMW

Through the Sediment Master Plan, CSMW has identified an array of information needs such as scientific and technical tools for assessing sediment transport, inconsistent regulations and policies, and local economic, social, and environmental issues associated with sediment management. These issues can be viewed as opportunities or obstacles in moving the paradigm. The CSMW has aggressively moved to address each of the identified issues and is developing tools to meet those needs.

Provided below are CSMW’s accomplishments through 2013\(^\text{13}\). The reader should understand that these products are addressing issues identified in the development of the Sediment Master Plan and are essential to moving forward in implementing a systematic approach to sediment management along the California coastline. The products are listed in four categories: information documents (Box 18), computer-based tools (Box 19), outreach (Box 20), and RSM plans for specific coastline areas (Box 21). See the CSMW website (http://dbw.ca.gov/csmw/default.aspx) for a more detailed discussion of each individual tool, document, or plan.

\(^\text{13}\) Author’s note: The long list of products included in this section would normally be placed in an Appendix to a report. However, they are listed in this section to emphasize the extent, type, and number of specific issues that have been addressed by the CSMW in a systematic approach to managing sediment and erosion issues.
**Box 18. Information Documents**

- **Policies, Procedures, and Regulations Analysis.** A draft analysis of federal, state, and local policies, procedures, and regulations (PPRs) affecting beach nourishment and related sediment management activities in California is being conducted as part of the Sediment Master Plan. These related activities include dredging and excavation, transportation, and placement of sediment in littoral cells throughout California. (1)

- **Development of Sand Budgets for California’s Major Littoral Cells.** Comprehensive review and compilation of dredging records and other relevant sediment source and sink information for each littoral cell to develop sand budgets. This informational document characterizes background conditions, so that coastal managers can assess the need for sediment and appropriate project size at a beach erosion concern area. (2)

- **Beach Restoration Regulatory Guide.** This informational report and strategy was prepared to help clarify the regulatory process and requirements for sediment managers and provide guidance for local coastal stakeholders. (2)

- **Sources, Dispersal, and Fate of Fine Sediment Supplied to Coastal California.** This report provides a megaregional analysis on the natural transport and volumes of fine-grained materials to and within the ocean. This informational report provides background for comparison against sediment management projects, and begins the understanding of fine sediment fate and transport in the ocean as a means to address a potentially major impediment to regional sediment management. (2)

- **Cumulative Loss of Sand Due to Dams.** An analysis of the amount of sediments captured by dams in California coastal watersheds. (1)

- **California Beach Erosion Assessment Survey 2010.** This informational report and strategy identifies critical coastal erosion locations, known as beach erosion concern areas (BECAs), where beach erosion has been of concern to jurisdictional entities. The report also identifies locations of excess sediment, including ports, harbors, wetlands, and flood control projects, that could be used to address erosion through RSM applications. October 2010.

- **Regional Sediment Management—Offshore Canyon Sand Capture.** This informational tool identifies submarine canyons along the California coast where artificial measures to reduce or eliminate the amount of sand being lost and whether recovery of that sand for beach nourishment activities might prove cost-effective and environmentally benign. 2009.

- **The Economic Costs of Sea Level Rise.** The report “The Economic Costs of Sea Level Rise to California Beach Communities” was prepared in September 2011 to provide an analysis of the economic implications of rising sea level on five representative California coastal community beaches.

- **The Economics of Regional Sediment Management in Ventura and Santa Barbara Counties.** (2)

- **Sand Compatibility and Opportunistic Use Program Pilot Project Mitigated Negative Declaration.** (2)

*Products, documents, or actions without a specific year were produced: (1) pre-2006, (2) 2006-2009, or (3) 2009-2012 as noted in the 2012 Sediment Master Plan.*
Box 19. Computer-Based Tools and Reference Materials

- **CSMW Website.** The website is continually upgraded to include new developments and information (www.dbw.ca.gov/csmw/default.aspx). (1)
- **Coastal References Compendium and Searchable Database.** Allows for the electronic search of references compiled for the Coastal Reference Compendium and subsequent CSMW products (including completed Coastal RSM plans) by region, author, title, and various subject categories. (1)
- **Literature Search.** A literature search and review of selected topics related to coastal processes, features, and issues in California. (2)
- **California RSM Information System.** This staging repository for relevant spatial data includes information obtained by CSMW from numerous sources, as well as various data layers created specifically for CSMW efforts. (2)
- **Web-based Spatial Data Mapping Tool (WebMapper).** User-friendly viewer developed to display spatial data, relevant to sediment management issues and compiled in the CRSMIS Geographic Information System (GIS) database (http://coastalsediment.resources.ca.gov/map). (2)
- **GIS User’s Survey.** In coordination with a state-wide group of experienced GIS users in the coastal realm, the CSMW funded an effort to identify improvements that would make the CSMW WebMapper and associated GIS-based online tools more useful. The Final Report, completed in July 2011, contained recommendations for implementation.
- **Tijuana Estuary Sediment Study/Demonstration Project.** This RSM demonstration project was designed to provide a science-based approach to determine the suitability of beneficially using clean upland sediment with a relatively high percentage of fines for restoration within the coastal nearshore. The project was conducted at two sites, the Tijuana Estuary from the mouth of the Tijuana River to the International Border and the Santa Cruz Harbor adjacent to the mouth of the Santa Cruz Harbor. A sediment-transport model was confirmed by the study. (3)

*Products, documents, or actions without a specific year were produced: (1) pre-2006, (2) 2006-2009, or (3) 2009-2012 as noted in the 2012 Sediment Master Plan.*
Box 20. Outreach*

- **California Sediment Master Plan Brochure.** A four-page brochure presenting the issues of sediment management, beneficial uses of dredged material, and the CSMW. [http://dbw.ca.gov/csmw/PDF/SMP_Brochure.pdf](http://dbw.ca.gov/csmw/PDF/SMP_Brochure.pdf) (1)
- **Public Outreach Program.** The Public Outreach Program is an integral part of the CSMW efforts, including sponsoring Stakeholder Advisory Groups in each of the regions where RSM plans are being developed. Numerous workshops have been held on specific and regional sediment management issues, and a public outreach contact list is maintained on the CSMW website to ensure consistent communication and coordination with the public and stakeholders. (1)
- **Littoral Cells, Sand Budgets, and Beaches.** Layman’s explanation of the physical processes involved in building beaches and the issues and considerations involved when artificially nourishing them. This educational tool is meant to educate concerned stakeholders who are unfamiliar with beach genesis and coastal processes. (2)

*Products, documents, or actions without a specific year were produced: (1) pre-2006, (2) 2006-2009, or (3) 2009-2012 as noted in the 2012 Sediment Master Plan.

Box 21 provides a summary of RSM plans that have been completed or are currently in development. The RSM plans seek to prepare region-specific strategies to resolve sediment imbalance issues within a particular region, and then to weave the regional strategies together to form the basis for a state-wide systems approach to sediment management. RSM plans are intended to *restore, preserve, and maintain coastal beaches and other critical areas of sediment deficit; sustain recreation and tourism; enhance public safety and access; restore coastal sandy habitats; and identify cost-effective solutions for restoration of areas impacted by excess sediment* (http://dbw.ca.gov/csmw/crsmp.aspx).

Each coastal RSM plan includes:
- A recommended governance structure best suited to implement recommendations within the plan;
- An outreach program to insure participation by most stakeholders and the public;
- An assessment of physical conditions (erosion, sedimentation, sand transport patterns, etc.) within the plan boundary;
- An economic analysis of benefits and costs associated with sediment management within the plan area;
- An assessment of the environmental conditions within the plan area, including sensitive biota and habitats; and
- Geospatial data layers of gathered information suitable for inclusion in CSMW’s geospatial database and WebMapper.
Box 21. RSM Plans, Support Documents, and Programmatic Environmental Impact Reports

- **Southern Monterey Bay Littoral Cell.** This was the first plan to be developed and adopted through CSMW’s regional effort. The plan identifies the most current understanding of physical processes, biological occurrences, recommended activities, and strategies for implementing sediment management from Moss Landing to Point Piños. The Association of Monterey Bay Governments (AMBAG) adopted the plan in 2008.

- **Santa Barbara Littoral Cell.** Details the physical processes and suggested projects, activities, and strategies to implement sediment management in the Santa Barbara Littoral Cell. BEACON adopted the plan in 2009.

- **San Diego County.** Provides comprehensive analysis of potential receiver sites, biological occurrences, and strategies to address sediment deficits for the Silver Strand, Mission Bay, and southern Oceanside Littoral Cell, from Camp Pendleton to the Mexican Border. The San Diego Association of Governments (SANDAG) adopted the plan in 2009.

- **Orange County Littoral Cells.** The Parks Department of Orange County completed its plan covering the littoral cells in Orange County in 2013.

- **Eureka Littoral Cell.** The Humboldt Bay Harbor Recreations and Conservation District is currently preparing its plan, covering Trinidad Head south to False Cape.

- **San Francisco Littoral Cell.** The Association of Bay Governments is currently working to develop its plan, covering Golden Gate Bridge to Pacifica.

- **Los Angeles County.** A draft plan for the coastline within Los Angeles County is under review, which addresses the governance structure for the coastal area.

- **San Francisco Central Bay.** The Bay Conservation and Development Commission is currently developing a plan for the central San Francisco Bay to the Golden Gate.

- **Santa Cruz Littoral Cell.** CSMW is working to partner with the Monterey Bay National Marine Sanctuary to conduct governance and outreach activities for the stretch of coast from Half Moon Bay to Moss Landing, while the physical, economic, and environmental elements are being compiled by USACE in-house subject experts.

- **Morro Bay/San Luis Obispo County, Crescent City/Del Norte County, and Sonoma County.** Each of these entities is exploring the possibility of preparing a coastal RSM plan.

- **BEACON’s Programmatic Environmental Impact Report.** The BEACON developed a programmatic environmental impact report (PEIR) to evaluate potential environmental impacts associated with nourishment and retention structures to minimize sand loss, as recommended in its Coastal Regional Sediment Management Plan (CRSMP). The Final PEIR was completed in March 2011.

- **Support Documents for a Programmatic Environmental Impact Statement (PEIS) / PEIR for SANDAG.** Two documents were produced to support the RSM plan for SANDAG: “Description of Proposed Action and Alternatives in Support of Preparation of a PEIS/PEIR” and the “Coastal Habitat Survey of Onshore and Nearshore Beach Receiver Sites Proposed in the CRSMP.” These documents were finalized in May 2010.

- **Southern Monterey Bay Coastal Erosion Workgroup (SMBCEW).** The CSMW is participating in the SMBCEW, which is currently evaluating various alternatives to address coastal erosion throughout coastal southern Monterey Bay, in addition to the sediment management options recommended in the CRSMP. The Final Alternatives Study was completed in April 2012.
In addition to the CSMW’s achievements to date, several products are expected to be finalized shortly:

- **Biological Impacts Analysis Reports:** The CSMW authorized this study to identify and assess biological impacts of coastal sediment management activities in California, and to develop recommendations to address relevant concerns as they relate to sensitive biota, habitats, or ecosystems. Two draft documents were released in 2012, Volume 1, Sediment Impacts and Issues, and Volume 2, User Guidelines and Resource Protection Guidelines (CSMW 2012a, 2012b).

- **Southern Monterey Bay Sand Management Plan:** The CSMW is working with the City of Monterey on developing a Sand Compatibility and Opportunistic Use Program to help the southern Monterey Bay region maintain beach widths through beneficial use of upland and coastal sediment. A Mitigated Negative Declaration (MND) will be prepared by the City of Monterey to address environmental issues associated with the program.

- **Orange County Sand Management Plan:** The CSMW is working with the Orange County Parks to develop a Sand Compatibility and Opportunistic Use Program to help the Orange County/Newport Bay region maintain beach widths through beneficial use of upland and coastal sediment. A Mitigated Negative Declaration will be prepared to address environmental issues associated with the program.

- **Surfers Beach and Pillar Point Harbor:** The CSMW is participating in a stakeholder workgroup to work with NOAA Sanctuaries, the Harbor District, surfers, and other stakeholder groups to address coastal erosion at Surfers Beach (also known as El Granada Beach) in Half Moon Bay, given strict regulatory limitations on placement of dredged materials within the Sanctuary.

- **Total Maximum Daily Load (TMDL) Development:** The CSMW is working closely with the State and Regional Water Quality Control Boards to facilitate the fluvial transport of coarse sediment needed to replenish coastal beaches while keeping fine-grained sediment contained so that it does not result in adverse impacts to fluvial, riparian, or coastal habitats. NOAA Sanctuaries are leading an effort to develop approaches that would allow for environmentally-sensitive sediment management activities within the boundaries of the Monterey Bay and Gulf of the Farallones National Marine Sanctuaries.

- **Depth of Closure:** The CSMW is working with the EPA to assess the merits associated with various definitions of depth of closure. The chosen definition will influence the EPA’s determination of whether individual dredged material placement projects are beneficially using sediment or conducting disposal activities.

Another significant action is the development of draft sea level rise guidance by the California Coastal Commission, released for public review in March 2013, intending to go final in 2014. The Guidance addresses the overarching question of how to integrate water level hazards associated with sea level rise into coastal planning efforts. The guidance complements the California Coastal Act, which provides enforceable provisions for coastal planning (CCC 2013).
Lessons Learned: Systematic Management of Erosion Issues and Sediments

As demonstrated by the list of products above, California is making substantial progress in developing the baseline information and tools needed to address erosion and accretion issues along the California coastline. Federal, state, local, and regional groups have identified sediment sources, developed sediment budgets, mapped out beach erosion areas of concern, and completed or are developing RSM plans. These efforts are consolidated in the Sediment Master Plan. Lessons learned to date are presented in Box 22.

Box 22. The Process and Lessons Learned

Key steps for systematic coastal sediment management reflect the challenges, information needs, and lessons learned, including:

- Collect data needed to characterize the coastal environment;
- Perform economic studies to determine the cost-effectiveness of potential projects;
- Develop tools to inform, educate, and promote littoral cell based (regional) sediment management;
- Disseminate new and existing tools to assist resource managers;
- Collaborate among agencies with shared and disparate missions including the OPC and West Coast Governors Agreement;
- Develop process-related guidance to help eliminate confusion with the regulatory process and streamline project permitting;
- Develop Regional General Permits and region-based environmental impact statement/reports for beach restoration;
- Expand available knowledge on, and best protective measures for, species and habitats of concern that could be affected by RSM activities;
- Encourage use of the Sediment Master Plan by California’s coastal sediment managers;
- Implement a public outreach program to identify and promote two-way communication with coastal stakeholders;
- Develop educational materials that will support sediment-based solutions and consideration of sediment as a resource rather than a waste; and
- Assist ports, harbors, wetlands-restoration groups, and flood-control agencies in resolving their sediment-related issues.

Addressing the Obstacles: Policies, Procedures, and Regulations

The CSMW is conducting an analysis of federal and state policies, procedures, and regulations with the objective of improving governance and restoring sediment imbalances along California’s coastline. The draft analysis recognized that comprehensive sediment and erosion management will require significant funding and modified governance. The analysis noted that other coastal states with successful restoration histories have developed comprehensive state-level programs that use focused governance and dedicated funding to restore their affected coastal habitats. This dedicated funding allows these programs to attract and leverage federal funding. The analysis also noted the critical need to inform and educate stakeholders regarding the sediment supply crisis, and the tools needed to assist governance efforts at restoring sediment imbalances.

Because the analysis is still in draft form and CSMW has not made final recommendations, the 10 recommendations from the draft document might change (Box 23). They are provided in this document to give a perspective on the types of actions under consideration. The CSMW has not endorsed these
recommendations, and they are not findings, conclusions, or recommendations of this report. For more information, contact the CSMW.

**Box 23. Preliminary Considerations by CSMW for Improved Governance and Restoring Sediment Imbalances**

1. Establish a dedicated source of funds for the Public Beach Restoration Program that will attract increased local and federal participation and funding for beach restoration.

2. Modify federal policy regarding the importance of public recreation associated with the analysis of benefits and costs associated with beach restoration projects.

3. Develop ways to expedite the USACE reconnaissance and feasibility study process.

4. Amend California Environmental Quality Act (CEQA)/National Environmental Policy Act (NEPA) guidelines to include consideration of impacts to beach sand supply for all projects and activities within the coastal zone or watersheds, or develop regional programmatic EIRs for sand supply projects to assist local governments within those regions in assessing and proposing these projects.

5. Establish a state Coastal Sediment Management Office to disseminate information, coordinate activities, and assist local governments with sediment management issues.

6. Propose state legislation to require restoration for beach erosion caused by sand mining and state navigation, flood control, and water storage projects, including effects associated with sea level rise.

7. Change definition of “sediment as a pollutant” to “fine-grained sediment as a provisional pollutant.”

8. Propose legislation to authorize the federal government to nourish or restore beaches affected by erosion caused by all federal projects including flood control and water storage, or contribute to a state-mitigation fund that can undertake beach nourishment and restoration.

9. Utilize the TMDL component of the Clean Water Act to establish criteria for delivery of sediment to the ocean.

10. Pursue measures to increase or restore natural sediment supply to the coast. *(Note: Presumably, this would be a mission of the State Coastal Sediment Management office.)*

*Not endorsed by CSMW; not a finding/conclusion/recommendation of this report.*
7. CASE STUDIES OF EROSION AND ACCRETION ON THE CALIFORNIA SHORELINE: ECONOMIC, SOCIAL, ENVIRONMENTAL, AND POLICY ISSUES

The following case studies highlight the social, economic, and environmental implications of shoreline change. They represent a range of issues that occur along California’s coastline and are organized by region (Figure 33). See the table of contents on the following page for assistance in navigating through the 15 case studies.

Figure 33. Map of case study locations.
## Case Studies of Erosion and Accretion on the California Shoreline:
**Economic, Social, Environmental, and Policy Issues**

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Northern California Shoreline

Crescent City Harbor

Issue: Post-tsunami accretion in Crescent City Harbor

![Figure 34. Damaged boats in Crescent City Harbor after first tsunami surge. Source: Bryant Anderson/AP](image)

**Background:** While tsunamis do not frequently occur along the California coast, they are a concern given the seismic activity in the western region of the Pacific Ocean and on the Eastern Rim of the Pacific Ocean. The March 11, 2011 tsunami, that originated offshore of Japan, is the fifth tsunami to seriously damage Crescent City in less than 80 years (Figure 34). The tsunami deposited approximately 75,000–78,000 cubic yards of sediment in the Crescent City harbor, leaving it as shallow as 4 feet in some locations. Twenty-six boats were destroyed and boats greater than 15 feet long were unable to access the harbor.

**Cost:** Initial estimates for harbor dredging, which depended on where the material would be deposited, were $7.8 million for inland placement or $4.5 million for offshore placement. Local officials decided to put the dredged material offshore of Eureka. The harbor was re-built by 2014 at a total cost of $50 million, including the construction of a tsunami attenuator dock built to withstand a 12 to 15 foot wave.

**Socio-Economic Issues:** Crescent City is the largest Dungeness crab exporter on the West Coast. For a city that was already facing an unemployment rate greater than 13 percent and economic challenges due to the closure of several lumber mills and fish processing facilities, the loss of a crabbing season because of harbor accretion could have been economically devastating. Delays in securing dredging permits and funding in the aftermath of the tsunami forced many fishermen to move their boats to Fort Bragg, Monterey, or Oregon's Coos Bay rather than wait for the Crescent City harbor to be dredged and reopened. Luckily, the port cobbled together temporary docks allowing for over 9 million pounds of crab to be hauled during the 2011-2012 season.
References:


Eureka and Redwood City

Issue: Separate conflicts in Redwood City-San Mateo County and in Eureka–Humboldt County over development in areas predicted to face rising sea levels

Note: two case studies are presented.

Background: Coastal erosion, exacerbated by sea level rise, will likely erode bluffs and inundate coastal beaches and marshes. The National Research Council (2012) determined that state agencies should prepare for a 9-inch increase in sea level by 2030, more than a foot-and-a-half of rise by 2050, and sea levels almost 5 feet higher by 2100. The State and many communities are addressing the challenge of eroding shores and rising seas by mandating that new development plans address sea level rise and associated coastal erosion in the project-design phase.

Development proposals in Eureka and Redwood City have raised issues regarding how best to implement project designs that address rising sea levels and associated increases in coastal erosion, and whether those designs should incorporate shoreline protection structures, less buildable land, or both. In Redwood City, salt has been harvested on a 1,400-acre coastal property for over 100 years. The current owner and operator has been working with a developer to convert the area into the “Redwood City Saltworks,” a development project initially planned to have 8,000–12,000 new housing units. Half the site would be dedicated to permanent open space, recreation, and restored tidal marsh. The development plan includes a 3-mile levee to protect the project from rising water levels in San Francisco Bay. The project developer is in the process of scaling-back the initial proposal.
In an example from Northern California, a developer in Humboldt County has been attempting to develop a mixed-use town (Samoa) on a 220-acre site on a narrow peninsula just west of Eureka for over a decade. But state studies have shown the area is highly susceptible to tsunamis and storm waves, which can accelerate erosion. Additionally, the predictions for sea level rise render the area extremely vulnerable to future flooding. The California Coastal Commission approved the Samoa land use plan in the spring of 2011 with conditions to ensure the property owner is aware of, and prepares for, sea level rise.

**Cost:** Although costs are case-specific, projects affected by new planning mandates will likely require additional site design work and will face increased material and labor costs associated with constructing structures farther away from the sea with elevated first floors in some cases. Developers may not be able to realize the expected economic potential of their parcels because of new building restrictions based on local erosion and sea level rise estimates. Since sea level rise is only beginning to be considered in land-use planning, and there are uncertainties and start-up costs associated with early development of best management practices, these initial projects may face higher permitting and design costs that future projects may not have to address. In Humboldt County, the developer paid $100,000 to consultants for a study that showed the planned habitable space in the project must be elevated to 32 feet to avoid risks due to future tsunamis and sea level rise.

**Socio-Cultural Issues:** For many, these cases are perceived as pitting short-term private economic interests against the long-term public interests associated with storm damage prevention, the cost of federal flood insurance, and preservation of vulnerable coastal habitat and its associated economic value tied to the fishing and tourist industries.

- Many environmentalists are critical of shoreline armoring because it changes the ecosystem habitat of the natural shoreline, is aesthetically displeasing, sometimes inhibits beach access, and can result in passive erosion. Recent studies, as noted before, have found the experiences of beachgoers are neither positive nor negative in relation to armoring.
- Development interests tend to be concerned about the uncertainty of future coastal-change estimates and usually desire flexibility in designing ways to address the issue to maximize their return on investment.

These cases highlight the conflicts that arise when strategic planning objectives (especially new policies with significant land-use implications) clash with an economic model based on a quick, predictable, and profitable return on investment. This situation is known as a social trap, in which individuals are tempted by actions that have immediate benefits to them, but come with long-term costs to many.

**References:**


Central California Shoreline

Ocean Beach

Issue: San Francisco Outer Coast. Social conflicts associated with a public entity charged with balancing several public interests in the face of an eroding shoreline

Background: Ocean Beach is a 3.5-mile sandy beach on the outer coast of the city and county of San Francisco. While the beach itself is part of the Golden Gate National Recreation Area, most of the infrastructure on the landward side is part of the city and county of San Francisco. The beach is backed by parking areas and a roadway (the Great Highway), which runs along the entire length of the beach. Ocean Beach serves as a major recreation center for San Francisco residents and tourists from around the world, provides habitat to two threatened bird species, and houses major elements of the city’s wastewater and stormwater infrastructure. Ownership and management of the beach and surrounding land is complex and involves several entities:

- The U.S. National Park Service is the landowner of the Golden Gate National Recreation Area, and overall manager of the beach, dunes, and select public access amenities only.
- San Francisco Department of Public Works manages roadways and infrastructure.
- San Francisco Recreation and Parks Department manages the nearby Golden Gate Park and the multi-use pathway.
- San Francisco Public Utilities Commission manages the Oceanside Wastewater Treatment Plant and sewerage system (e.g., underground pipes and pumps).
- San Francisco Zoo (City of San Francisco and the San Francisco Zoological Society) abuts the beach, leasing land from the San Francisco Recreation and Parks Department.
- Other adjacent landowners include businesses and residences.

Large fluctuations in the position of the shoreline along Ocean Beach have been documented in coastal survey charts and maps since the mid-1850s (Olmstead and Olmstead 1979). Long term observations of shoreline change indicate accretion along the northern portion of Ocean Beach and erosion along the southern stretch of Ocean Beach; the position and size of the ebb tidal delta just outside the Golden Gate National Recreation Area plays a major role in affecting wave energy and sediment dynamics along the beach. Human alteration of the shoreline has occurred since the western edge of the city was first developed starting in the 1860s, and the Great Highway was established as a roadway and esplanade along the beach.

Many of the earliest erosion control measures were taken to protect the Great Highway. Methods to control erosion have included construction of seawalls and dunes, placement of rocks and concrete debris, and sand bypass. Since the mid-1990s erosion along the south stretch of Ocean Beach has increasingly threatened the roadway, parking lots, and city wastewater infrastructure. In 1997, the San Francisco Department of Public Works installed an un-permitted 600-foot-long “Emergency Quarrystone Revetment” at the south end of.
the beach, followed in 1999 and 2010 by additional emergency shoreline protection activities. All of those structures were aimed at protecting the recreation facilities, public access, existing roadway, parking lots, and wastewater treatment infrastructure.

During the winter of 2009–2010, bluff erosion caused the partial collapse of a section of the Great Highway, which subsequently reopened with only one of its two southbound lanes usable. An emergency permit was issued for a 425-foot-long riprap revetment to stabilize the erosion, but 440 feet were installed. The San Francisco Department of Public Works applied for after-the-fact permits from the California Coastal Commission for the erosion mitigation activities that occurred in 1997 as well as for the placement of 15 extra feet of revetment. At a July 2011 meeting, the Commission unanimously rejected the permit application. On the heels of the permit rejection, a lawsuit was filed by the California Coastal Protection Network that sought removal of the rock revetment and development of long-term shoreline stabilization plans. The California Coastal Protection Network claimed the city of San Francisco had been in violation of the California Coastal Act for 14 years by violating terms of emergency permits and impeding beach access. In 2014, the city reached a settlement with the California Coastal Protection Network for $125,000.

In 2012, the San Francisco Bay Area Planning and Urban Research Association (SPUR), a public-policy think tank, completed the Ocean Beach Master Plan, following an 18-month long public planning process. This non-regulatory plan proposed solutions for the management and protection of San Francisco’s Ocean Beach. Key long-term recommendations included re-routing the most vulnerable section of the Great Highway along south Ocean Beach, replacement of that section with a coastal access trail that would allow bluff and beach erosion while incrementally removing the road and parking lots, and protection of the wastewater tunnel with a low profile hardened structure.

Short-term protection strategies included sand back pass and the placement of sandbags to stabilize the toe of the bluffs. In 2012, a sand back pass project was completed and 58,000 cubic yards of sand was hauled from the north end of the beach to the erosion hotspot south of Sloat Boulevard. Similar efforts were repeated in 2014, 2015, and 2016.

Beach nourishment is another strategy that is being considered. The USACE considered building a system that would pump 300,000 cubic yards of dredged sand from channels by the Golden Gate Bridge to the erosion zone. The effort would "bury the existing rocks out there and construct a sand dune which would resemble other sand dunes out there," said Peter Mull, project manager for the USACE. "If there's an El Niño five minutes after ... it's most likely going to be gone," Mull said. This approach is estimated to cost $5 million to $8 million and last at most five years, assuming there is not an El Niño.

**Cost:** The Surfrider Foundation estimates the cost of studies, analyses, and construction costs of the revetments since 1997 has totaled at least $5 to 7 million. The total cost of the SPUR plan is estimated at $343 million.

**Socio-Economic Issues:** This case has social, legal, technical, and economic implications that exemplify the difficult issues public entities face in balancing multiple public interests and responding to short-term emergencies, while not immediately addressing the need for longer-term sustainable solutions. In terms of economic implications, the city of San Francisco has already spent millions of dollars seeking temporary solutions, which (some argue) may have been avoided or mitigated by the development of a longer-term
shoreline plan involving relocation of infrastructure. On the other hand, infrastructure like the wastewater treatment plant represents over a billion dollars in public investment and has significantly improved coastal water quality. The city will have to shoulder costs associated with future planning, design, and implementation of a longer-term solution.

Aside from the economic and legal implications, this case involves social conflicts associated with a public entity charged with balancing several public interests in the face of an eroding shoreline. Social conflicts include perceptions held by some that in implementing its mission to protect infrastructure, the city is interfering with public recreation both onshore and in the water, and has been doing so without the benefit of regulatory review and its associated public participation process. Surfers claim that the surf break just offshore is being degraded by wave refraction caused by the erosion control measures, but others question this conclusion.

Another approach to protecting the bluff, which will protect the valuable infrastructure, is to nourish the beach from the nearshore or by building sand structures in front of them. In 2005, USACE relocated the placement site for sand dredged from the San Francisco Main Ship Channel from a location on the large, ebb-tidal bar seaward of the Golden Gate to a nearshore site seaward of the southern, periodically-eroding stretch of Ocean Beach. Between 2005 and 2012, USACE placed 2.3 million cubic yards of sand at that site in depths greater than 35 feet mean lower low water. The placement site was chosen because its proximity to the erosional area might result in onshore migration of sand to the nearshore zone or beach, thus providing a buffer to erosion that peaks during winter months when large waves remove the beach sand and directly attack the bluff. However, before and after dredge surveys do not show a direct link to nourishment of the beach. Conclusions from the study conducted by Hansen (2009) were that placement in the littoral zone at less than 16 feet deep were needed to drive a positive shoreline response. Another supposition is that the placed sand increases wave-energy dissipation before the waves reach the bluff. No information is available on the effect of the nearshore sand placement on the quality of the surfing.

This is a complex issue, not completely captured in this case study. Instead, the point of this case study is to illustrate the difficulties in managing a beach for multiple human uses in an urban setting, where multiple agencies have overlapping jurisdictions and boundaries, multiple user groups are competing for limited space, and critical infrastructure is threatened.

References:


Crissy Field of San Francisco Bay

Issue: Sea level rise and coastal erosion threaten restoration project at Crissy Field, San Francisco Bay.

Background: Crissy Field is located in the Presidio of San Francisco along the northern San Francisco Bay shoreline in what is now the Golden Gate National Recreation Area. It includes nearly a mile of sandy beach backed by dunes, a 1.5-mile long pedestrian promenade, a restored tidal marsh and the re-creation of a historic airfield. Historically, Crissy Field was part of an extensive 127-acre dune and tidal marsh ecosystem that drained to San Francisco Bay. From 1846 through 1994, the Presidio was a U.S. Army base and the Army began filling portions of Crissy Field in the 1870s to reclaim land for development. The area was transferred to the National Park Service (NPS) in 1994, although portions of the shoreline had already been placed under the care of the NPS in 1973.

Crissy Field has undergone an amazing transformation. Today, the area is a popular local park. Thousands of people stroll down the Crissy Promenade every week, and the area supports diverse coastal flora and fauna. The restoration re-created an 18-acre tidal marsh linked to San Francisco Bay, as well as 16 acres of dune habitat. Many thousands of cubic yards of dirt, sand, and mud were excavated. A sea channel was opened in late 1999, allowing fresh and salt water to merge at Crissy Field for the first time in 100 years.
Immediately following creation of the tidal marsh in 1999, sand began depositing in the tidal inlet connecting the new wetland with San Francisco Bay (Battalio et al. 2007). The newly restored tidal marsh acted as a sediment sink, reduced wave-driven sand supply to the adjacent “East Beach” and resulted in erosion of the beach. Crissy Field’s East Beach is a popular wind-surfing destination and erosion exposed buried rubble and concrete debris, causing health and safety concerns for beach visitors. Beach erosion also threatened to undermine the pedestrian promenade backing the beach. In response, protective measures were implemented including two small scale beach sand replenishment projects and the burial of “K-rail”, the movable barriers used on freeways, as an emergency barricade to protect the promenade. By 2002, the K-rails were buried by naturally deposited sand, and the beach had recovered. This sand deposition was attributed to the growth of an ebb-tidal shoal at the mouth of the new wetland. Monitoring data from 1999 to 2007 indicated accumulation of approximately 20,000 cubic yards per year (Battalio et al. 2007).

Figure 35. Left is photo of Crissy Field years ago and right shows potential for a flood event at 1.4-meter sea level rise. 
Source: USGS / National Archives

Figure 36. Crissy Field, San Francisco wetland and shore enhancement. East Beach before the project (left) and after (right).

Note: The vertical piles anchoring a storm drain outfall are visible in both pictures. The post-project picture shows the beach scarp in the erosion “hotspot.” The inlet is in the background where small waves are breaking. The beach has widened significantly following a brief period of erosion immediately after the restored marsh was connected to the Bay. (Source: ESA Philip Williams and Associates, Ltd.)
**Cost:** The cost of the restoration project at Crissy Field was $32 million. The cost of the post-construction erosion mitigation was approximately $75,000. The erosion mitigation is now buried in a much wider beach than existed pre-project, and no further action is anticipated.

**Socio-Cultural Issues:** Crissy Field is an example where restoration of natural habitat has resulted in increased beach recreation. The project accommodated pre-project uses including wind surfing activity, but also provided additional visitor facilities to support other recreational uses. In the San Francisco Bay area, it is predicted that $36 billion worth of shoreline development (almost 180,000 acres) will be at risk of flooding by mid-century (BCDC 2011). The question that state and local officials must eventually address in the face of rising seas, is whether natural shoreline protection or more engineered strategies will have the greater payoff. Additionally, officials may have to consider whether the loss of beach recreation opportunities and natural habitats in such a densely developed area is an acceptable tradeoff for greater protection of critical infrastructure and property. Currently, most of the infrastructure at Crissy Field is set back from the shoreline behind the beach, dunes, and marsh. However, there is only limited space for these habitats to migrate inland as they are backed by a roadway (Mason Street) which is a major utility corridor. As sea levels rise, the beach at Crissy Field will narrow and steepen, and the tidal marsh will eventually be drowned unless infrastructure is abandoned or relocated. Some park elements, such as the shoreline promenade may need to be relocated sooner.
References


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**Hamilton Airfield Wetland Restoration Project of San Francisco Bay**

**Issue:** Beneficial use of dredged material to restore wetlands in San Francisco Bay

**Background:** In and around San Francisco Bay (Bay), 3 to 6 million cubic yards of sediment must be dredged every year by USACE and others to maintain safe navigation. Prior to 2000, 80 percent of the dredged material was disposed of in the bay, 10 percent in the ocean, and 10 percent onshore (upland). The majority of the dredged sediment was deposited near Alcatraz Island (just inside of the Golden Gate Bridge), a practice that created concerns over potential impacts to water quality and wildlife within the bay. In 2000, the San Francisco Bay Long Term Management Strategy (LTMS), a cooperative effort between the EPA, USACE, the San Francisco Regional Water Quality Control Board, the BCDC, and local stakeholders implemented the LTMS Management Plan, an innovative approach for using dredged material in the bay area. Starting that year, the volume of dredged material that could be placed in the bay was set at 2.8 million cubic yards a year (plus 250,000 cubic yards contingency to cover unforeseen events). Every three years, the maximum volume of dredged material that could be placed in the bay was reduced by approximately 387,500 cubic yards. The LTMS goal of a maximum of 1.0 million cubic yards (plus contingency) per year was reached in 2012. In any given year, the desired disposal distribution is 40 percent in the ocean, 40 percent upland, and 20 percent in the bay.

One of the four objectives of the program are to “maximize the [re]use of dredged material as a resource.” One of the ways dredged material is reused is through wetland restoration projects. These projects, such as the Hamilton Wetland Restoration Project, involve placement of dredged material in baylands that have historically been diked and, as a result, have subsided. Raising the elevation of this land allows wetland vegetation to re-establish and the wetland to be restored. The Hamilton Army Airfield, which closed in 1994, was selected as a restoration site as part of the LTMS. Fill has already been added to restore site elevations which will accelerate the timeframe for marsh development. Seasonal wetland, transitional habitat, and upland areas will fringe tidal marsh (Figure 37). The 2,600-acre project encompasses the Hamilton Army Airfield (which includes a former Navy ball field and a State Lands Commission parcel totaling approximately 1,000 acres), as well as the approximately 1,600-acre Bel Marin Keys Unit V parcel. In April 2014, the bayfront levee was breached and connected the former airfield property to the bay for the first time in more than...
100 years, enabling the process of ecological succession to tidal marsh. The Bel Marin Keys V component has no completion date scheduled at this time.

The Hamilton Wetland Restoration Site received around 5.8 million cubic yards of dredged material from in-bay federal navigation channels though the USACE Operations and Maintenance Program, most of which came from the Port of Oakland dredging project. A list of projects contributing to the Hamilton Restoration, totaling nearly 3 million cubic yards, are shown in Table 18.

**Cost:** The Hamilton wetland restoration project was first authorized as a federal project in the 1999 Water Resources Development Act at a total cost of $55 million, and the Bel Marin Keys Unit V component was added to the project in the 2007 Water Resources Development Act for a new total cost of $228 million.

**Socio-Economic Issues:** As mentioned in the Crissy Field case study, San Francisco Bay will be facing potential large-scale losses with projected rises in sea level. The LTMS is a good example of innovative, cost-effective strategies that allow local, state, and federal agencies the opportunity to address both accretion and erosion within one project. In the future, the availability of sediment from dredging navigational channels may aid in sustaining the bay shoreline through nourishment or wetland restoration. However, these “softer” approaches to address erosion may not be possible or desired along the more heavily developed portions of the bay.

*Figure 37.* Aerial imagery of the Hamilton Wetland Restoration Project site from December 2003 (left) and October 2009 (right).

*Source: Google Earth/US Geological Survey/USDA Farm Service Agency*
Figure 38. Oblique aerial view to the south-southwest of the former Hamilton Air Force Base
Source: Wikimedia Commons

Table 18. USACE operations and maintenance dredging projects contributing dredged material to the hamilton wetlands restoration project.
Source: USACE San Francisco District

<table>
<thead>
<tr>
<th>Project</th>
<th>Fiscal Year</th>
<th>Volume Placed (cubic yards)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oakland Harbor</td>
<td>2008</td>
<td>355,000</td>
</tr>
<tr>
<td>Pinole Shoal</td>
<td>2008</td>
<td>34,000</td>
</tr>
<tr>
<td>Oakland Harbor</td>
<td>2009</td>
<td>344,000</td>
</tr>
<tr>
<td>Redwood City Harbor</td>
<td>2009</td>
<td>436,000</td>
</tr>
<tr>
<td>Richmond Harbor</td>
<td>2009</td>
<td>388,000</td>
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<td>Oakland Harbor</td>
<td>2010</td>
<td>867,000</td>
</tr>
<tr>
<td>Richmond Harbor</td>
<td>2010</td>
<td>278,000</td>
</tr>
</tbody>
</table>

References:


Pacifica Armoring and Retreat—Monterey Bay

**Issue:** Addressing erosion in Pacifica through armoring and retreat

![Image](image.jpg)

**Figure 39.** Armoring of an eroding Pacifica bluff, 2010.  
*Source: Bob Battalio, PWA*

**Background:** Bluff failure in Pacifica has been an ongoing concern for local and state officials. In 1983 (an El Niño year), a rock revetment was built at the cliff base to protect the houses along the Esplanade (Figure 39). Following the 1997–1998 El Niño, homes were damaged or demolished as the rock revetment settled on the sandy beach. Eroding bluffs, which are made of poorly-consolidated alluvium rather than bedrock, continue to plague the beachfront homes of Pacifica despite the variety of armoring efforts made by property owners.

Pacifica State Beach in Linda Mar illustrates a different experience. Managed retreat was implemented in 2005 by the city of Pacifica in cooperation with the California State Coastal Conservancy, California State Parks, and other government agencies (Figure 40). Pre-project development extended shoreward to the seaward limit of the two remaining coastal structures. Several buildings and parking lots were demolished, fill removed, and dunes re-graded and stabilized with vegetation.

![Image](image2.jpg)

**Figure 40.** Pacifica State Beach after implementation of managed retreat. The San Pedro Creek mouth is located near the far end of the beach where the wet-dry line extends landward.  
*Source: City of Pacifica 2005*
Before managed retreat, storm damage led to the construction of a rock revetment. The potential for erosion was exacerbated by fill and development immediately adjacent to the shoreline (RHAA 1990; PWA 2005). Managed retreat was facilitated by public ownership of much of the land, and the development of a State Park Management Plan that emphasized natural resources protection (RHAA 1990). Subsequently, the California State Coastal Conservancy funded implementation of the Management Plan by the City of Pacifica. The project, which has performed well, is a regional resource for the San Francisco area. It was awarded America’s Best Restored Beaches 2005 by the American Shore and Beach Preservation Association.

**Cost:** Private property owners have funded armoring in Pacifica and therefore costs are not readily available. For one abandoned apartment building, it was estimated that $600,000 in forfeited rent was lost over a period of 18 months. Government funding was used to implement the Pacifica State Beach project, which included purchase of two homes at a cost of $2.2 million.

**Socio-Economic Issues:** Pacifica has become a “poster-child” for the incredible damage that storms and bluff erosion can cause. As such, it also may serve as an illustration of future conditions based on predicted sea level rise and erosion rates, or a real-life visualization tool that can be used to avoid such conditions elsewhere. People living in these threatened buildings undergo the stress and danger of waiting for an emergency permit to be granted or the possibility of being forced out of their homes because of unsafe conditions. When buildings are evacuated, building owners are left without rental income. The owner of the property should have been provided with full disclosure of the hazards and risks, and people who buy property in hazardous locations should realize that profits are not guaranteed.

The cost of continued bluff armoring is becoming prohibitively expensive, especially with the ownership base shrinking as buildings are abandoned. Owners along Esplanade Avenue in Pacifica initially came together to discuss erecting a single, continuous seawall that would protect a quarter-mile stretch of bluff, but negotiations broke down. Without public funding, several property owners have simply abandoned evacuated buildings. This presents a challenge for city officials who, as one building official commented to a newspaper, have “no playbook” for this situation. While USACE can partner with local governments to address some erosion problems, solutions are needed to benefit multiple properties or infrastructure, and benefits must exceed costs in preliminary financial studies. But this type of analysis demands both time and money on the part of local government officials who are faced with emergency situations that cannot wait for financial studies and federal government response. Federal Emergency Management Agency (FEMA) grants for cliff stabilization are restricted to public places where access has been disrupted. If a major disaster is declared, individual assistance for renters and homeowners can be activated.

**References:**


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**Pleasure Point Bluff of Monterey Bay**

**Issue:** Pleasure Point bluff stabilization

![Figure 41](image-url) A soil nail wall consisting of shotcrete or textured and colored gunite to match the natural rock was used to stabilize the cliffs along Pleasure Point.  
*Source: Gary Griggs / Santa Cruz Sentinel 2010*

**Background:** For decades, Santa Cruz County has been experiencing bluff erosion along East Cliff Drive at Pleasure Point. The erosion rate was six inches to one foot per year. Significant failures of the cliff faces began in 1994, resulting in the restriction of traffic along East Cliff Drive. A citizen task force was assembled to evaluate the issues and, based on the scenic and recreational value of the area, decided to move forward with securing funding for bluff stabilization. The project was not without controversy as surfers were fearful that surfing waves would be degraded (but when completed wave quality was not impacted). In 2004, the County required emergency stabilization of three failing crib walls along the bluff. Soil nail walls covered with shotcrete, which was sculpted and stained to mimic a natural cliff face, replaced the crib walls. Additional stabilization work was proposed and finally approved in 2009 (contingent on removal of rip-rap boulders and concrete rubble at the base of the bluffs) and consisted of 60,000 square feet of soil nail and shotcrete bluff stabilization structures, three concrete beach access stairways, and existing riprap removal from the beach (Figure 41).

**Costs:** The attempts to stabilize the bluffs along East Cliff Drive have cost the County approximately $10.5 million between 1988 and 2011.
**Socio-Economic Issues:** Tourists and residents alike enjoy visiting and living along the California shore for many reasons. Undeniably, sweeping ocean views and wide beaches factor into the enjoyment people experience in places like Pleasure Point. Once riprap and concrete rubble were removed from the beach, the County saw increases in beach attendance, in particular, by the elderly and young families, who lacked convenient access with armoring in place.

The value of a view has been acknowledged in many of the local coastal plans (LCP) and land use plans that have been adopted by counties and cities to guide development in the coastal zone. The General Plan for Santa Cruz County includes an entire section on “Visual Resources,” which specifies that shoreline protection structures must “use natural materials and finishes to blend with the character of the area and integrate with the landform” (Santa Cruz County LCP 5.10.7). The Santa Cruz County LCP acknowledges not only the value of the ocean view from the bluff tops, where people build their homes, but also the view from the beach and the water towards the bluffs, an important protection for the public’s enjoyment. At Pleasure Point, the seawalls have already begun collecting moss and other natural characteristics that allow them to blend in almost seamlessly with the naturally occurring bluffs.

**References:**


Sand Mining along Monterey Bay Shoreline

Issue: Sand mining implications for the shoreline of Southern Monterey Bay

Background: Southern Monterey Bay coastal sand mining operations date back to 1906, when the first mining project began near the mouth of the Salinas River. Over time, additional operations arose in the area, including the introduction of intensive drag-line sand mining in the surf and swash zones in 1940. At its peak, six sand mining operations were concentrated along Southern Monterey Bay, with three in Marina and three in Sand City. Mining removed a total of 75,000 to 230,000 cubic yards a year with an average of 150,000 cubic yards (Thornton 2007). All but one of the sand mining operations terminated in 1988 as USACE permits and state lands leases expired and were not renewed. In large part, this was a result of the connections that were made between the amount of sand being removed and the dramatic amount of shoreline erosion during the severe 1982-83 El Niño (Griggs, G.B. and Jones, G.D. 1985).

As of 2014, the only sand mining operation on the Southern Monterey Bay shoreline occurs in northern Marina (Figure 42). The estimated amount of sand that is extracted and processed is approximately 170,000 to 200,000 cubic yards of material per year, which is about the equivalent of the total amount previously mined by all the plants. Primarily, mining consists of removing sand from a man-made pond located just landward of the beach berm. A hydraulic dredge extracts sand that washes over and into the pond through wave action. Since the mining takes place away from the swash zone, USACE issued a “determination of non-jurisdiction,” which allowed the operation to continue. Although the dredging location is confined to the back beach, scientists believe that sustained mining there is a primary reason for ongoing, notable shoreline erosion rates in the Sand City and Marina region. In fact, that opinion is expressed in the CSMW Coastal Regional Sediment Management Plan for Southern Monterey Bay. The Coastal Commission delivered a “notice of intent,” a precursor to a cease-and-desist order, to the Cemex company in March 2016. However, investigating the sand mine’s activity is difficult because it was established before California’s Coastal Act of 1976, and many of the mine’s operations are grandfathered in.
One lesson learned is the necessity for the myriad of agencies to collaborate and determine who has jurisdictional authority (e.g., USACE, California Coastal Commission, Monterey Bay National Marine Sanctuary, Monterey County, or City of Marina) and what actions are needed.

**Cost, Socio-Economic, and Cultural Issues:** According to a mining spokesperson, as of 2006, the plant employed 20 people and contributed at least $1.25 million annually to the city of Marina through both taxes and payroll (Vasquez 2006). The sand composition ensures the continued high demand as a result of the high silica content and desirable shape, color, and texture. The sand is used across a variety of construction and industrial applications, as well as in water filtration systems. Discontinuing the dredging operations might still allow for continued mining of some back-dune areas, but would halt the majority of the production processes.

On the other hand, mining operations affect sand budgets for the entire Southern Monterey Bay Littoral Cell. Because of this, the bulk removal of material affects not just the beaches of the city of Marina, but also those of nearby Sand City and potentially more coastal areas as well. For example, the Sanctuary Beach Resort and the Marina Coast Water District buildings could benefit from the additional buffer from the increased sand supply. Thus, if the mining stops, shoreline erosion likely will abate, reducing associated negative impacts to local beach economies as well as potential lost real estate. If the mining continues, beach nourishment, which can be expensive, could be part of the solution to augment the net removal of sand from the littoral cell.

**References:**


**Stilwell Hall of Monterey Bay**

**Issue: Demolition of Historic Stilwell Hall**

**Background:** The demolition of Stilwell Hall began in 2001, as part of the decommissioned Fort Ord U.S. Army base in Monterey Bay. Stilwell Hall had to be demolished because severe bluff retreat left the building 11 inches from the edge. After years of cleanup of the decommissioned base, the area opened as a state park at the beginning of 2009 (Figure 43).

**Costs:** The costs associated with relocating and rebuilding Stilwell Hall were estimated to be more than $24 million. The demolition cost was $2.2 million. It is unclear whether this cost included the removal of 200 meters of riprap that had been placed on the beach.

**Socio-Economic Issues:** This is an unusual case where a manmade structure was removed to allow the beach to return to natural conditions. Although Stilwell Hall was a historic landmark, it had been abandoned since 1994 when Fort Ord was closed, making it less of a fixture in people’s minds and of little economic value to the community. Although demolishing it raised strong emotions because of its ties to General Joseph W. Stilwell, it would have been difficult to raise the necessary funds to move it. Considering the Hall had not been used for over a decade before it was demolished, the site will likely receive more visitors as one of California’s newest state parks given its birding potential and relative isolation. The most important outcome of the removal of the riprap and concrete from the shoreline in front of Stilwell Hall was the recovery of the beach. It is one of the best examples of both passive erosion and rapid beach recovery (i.e., within 12 months) (Figure 44).

**Figure 43.** Fort Ord Dunes State Park. Source: CA Department of Parks and Recreation

**Figure 44.** Stilwell Hall in 2004 in southern Monterey Bay at Fort Ord and after removal in 2005. Note the recovered sandy beach. Source: California Coastal Records Website
Northern California Shoreline

Surfers Point, Ventura

Issue: Balancing multiple shoreline uses at Surfer’s Point, Ventura with a combination of managed retreat and innovative engineering

Background: The area adjacent to the mouth of the Ventura River in the City of Ventura, known as Surfer’s Point, is a popular surfing spot because it is easily accessible and the waves are large and consistent. Since the early 1990s, approximately 1,800 feet of its south-facing shoreline has extensively eroded. Consequently, the Surfer’s Point Managed Shoreline Retreat Project was developed to maintain a usable public beach, protect the surf quality at ‘Stables’ surf break, improve the water quality of nearby stormwater runoff, return a more natural environment to the mouth of the Ventura River, and draw visitors to a unique, restored coastal area. Construction crews removed a nearly-destroyed bike path and revetment (Figure 45), ripped out a 120-space parking lot, created an underlying cobblestone berm, and topped the berm with sand. This geo-engineering solution is expected to give the wave-ravaged point 50 more years of recreational life. The project, which is the first of its kind in California, could serve as a model for other threatened public recreation sites along the coast.

Cost: $4.5 million (Phase 1 was funded at $3 million. Phase 2 has yet to be funded.)

Socio-Cultural Issues: Local officials initially suggested a buried seawall to address the erosion problem. Environmentalists and surfers fiercely objected, saying that armoring the shore would protect a parking lot at the expense of the beach and destroy the point break that generates the distinctive, surfer-friendly waves for which the site was named. This project is considered a successful example of managed retreat at a public recreation site, but the primary issue did not revolve around private property owners. Thus, while it is a successful example of managed retreat, it is not necessarily an approach to erosion that would be possible or accepted by private property owners. Regardless, this case displays California’s growing arsenal of tools to combat sea level rise and work collaboratively with stakeholders to protect recreational interests.
CALIFORNIA REGIONAL ASSESSMENT NATIONAL SHORELINE MANAGEMENT STUDY

Figure 45. Eroding bike path at Surfer’s Point.
Source: PWA

References:


**Mobile Oil Piers--near Ventura and Santa Barbara Harbor**

**Issue:** Construction of a multi-purpose reef for beach erosion control as well as recreation (surfing) and ecological enhancements

**Background:** The 1998 removal of the Mobile Oil piers located 12 miles north of Ventura (15 miles south of Santa Barbara Harbor) resulted in significant erosion of the beach between the two access trestles and the concomitant loss of a surfing break. Construction of a multi-purpose submerged reef is considered a demonstration project to determine if this kind of structure can primarily reduce shoreline erosion by dissipating wave energy through innovation in design, materials, and construction. In addition, ancillary benefits could include recreation and development of suitable marine habitat.

The project was undertaken for the USACE, Los Angeles District and Engineer Research and Development Center (ERDC) under a Board Agency Announcement (BAA) as part of the National Shoreline Erosion Control Development and Demonstration Program (Section 227). Government officials and stakeholders considered proposals for multiple sites within Southern California. Several were chosen to move to the 30 percent design phase for further consideration. Upon further review of those submissions, the multipurpose submerged reef at the Oil Piers site was chosen to be developed to 100 percent design. The project stalled after the 100 percent design due to hurdles in securing the necessary funding and project authorization.
This would not be the first artificial reef in California waters, but it would be the first multi-purpose reef with a primary goal of abating shoreline erosion. In 2000, the Surfrider Foundation initiated construction of a surf-enhancement reef at Dockweiler State Beach in El Segundo. Pratte’s reef was mandated by the California Coastal Commission to mitigate the effects of a groin installed perpendicular to the shore by the El Segundo refinery. The reef failed to enhance surf, and monitoring in the years following installation revealed the geotextile bags were deteriorating. It was removed in 2008.

Cost: The project cost for the multipurpose submerged reef at Oil Piers is estimated at $7 million. Recreation benefits have not been calculated, though a bigger beach is expected to increase the usability and recreational enjoyment of the area. The Surfrider Foundation spent $550,000 installing Pratte’s Reef and an almost identical amount ($551,000) removing it.

Socio-Economic/Cultural Issues: Project supporters believe that beach erosion mitigation efforts involving the use of an artificial reef will have the dual benefits of reducing erosion at the beach and creating a popular surfing break.

The final design of the multi-purpose submerged reef is an 18,000-cubic-meter reef located approximately 250 meters offshore, close to the southeastern end of the 240-meter beach compartment. The reef structure will have a crest approximately 100 meters long set to the depth of 0.27 meters mean low water, oriented at an angle of 55 degrees relative to the beach, and constructed of sand-filled geotextile bags.

Of the six, artificial reef efforts the project designer has installed around the world, the data is limited in terms of demonstrating a consistent surfable break, and the effects on erosion mitigation are debatable.

Although nearshore artificial reefs present a new approach for managing erosion and enhancing or mitigating lost surf, they are still experimental in nature, which means that the high costs of removal are as important a consideration as installation costs.

References:


Broad Beach of Malibu

Issue: Erosion of Broad Beach and restricted public access

Background: Coastal erosion has shrunk Broad Beach, which fronts a number of expensive Malibu-area homes, to a narrowing strip of sandy shoreline (Figure 46). Several short-term, emergency recommendations to protect those homes have been approved in the past several years, including a 1.1-mile concrete seawall and boulder barricades. At one point, homeowners banded together to purchase and place sandbags on the back beach (Figures 47 and 48). In 2011, a group of 123 homeowners formed the Broad Beach Geological Hazard Abatement District (GHAD)\(^{14}\) to address creation of a longer-term strategy.

The District’s current approved project plan is to import 600,000 cubic yards of sand by dump truck and placing it on top of the existing 4,150-foot revetment to create a wide beach backed by a dune system. Approximately 450,000 cubic yards of sand would be placed on the beaches and 150,000 cubic yards on the dunes. The project continues to face numerous obstacles including a lawsuit over the sand source and the routes the trucks will take.

Figure 46. Broad Beach.
Source: Ocean Blue Luxury Homes

Cost: The emergency rock wall installed in 2010 cost residents $4 million. The sandbag approach was initially estimated to cost approximately $60,000, but that was an underestimate. The integrated strategy with sand nourishment has already cost property owner’s $30 million (inclusive of design and permitting).

Figures 47 and 48. The wall of sandbags erected by homeowners along Broad Beach in Malibu reflects the imperiled state of the once-wide strip of sand, which is being swept away by waves and tides.
Source, left to right: Ken Hively / LA Times, Hans Laetz / Malibu Surfside News

\(^{14}\) GHADs are formed for the purpose of preventing, mitigating, abating or controlling geologic hazards and the structural hazards caused by geologic hazards.
**Socio-Cultural Issues:** Broad Beach has always been a confusing patchwork of public and private sand, and access conflicts are common. Security guards and sheriff’s deputies often relocate beachgoers found using private sections of the beach. Over the past 15 years, clashes between the beachgoers and private property owners have been exacerbated by unprecedented erosion of what is left of the sandy strip. Distrust of private property owners’ intentions by the public appears to be high, although the homeowners state this perception is unfounded and that their only intent is to protect Broad Beach so that the public may also use and enjoy it.

**References:**


Port of Long Beach

**Issue: Beneficial use of contaminated sediment in the Port of Long Beach**

**Background:** In 1997, the State of California enacted legislation to address concerns over dredging and disposal of contaminated sediments in the Los Angeles area, including two of the nation's largest ports (Los Angeles and Long Beach). The Contaminated Sediments Task Force developed a management plan that includes recommendations for disposal, including beneficial use. In support of the Task Force’s recommendations, the Port of Long Beach began to accept contaminated sediment dredged from a variety of sources including the former Long Beach Naval Complex, Marina del Rey, Lower Newport Bay, and the mouth of the Los Angeles River. In 2000, nearly one million yards of contaminated sediment were used to create a 30-acre landfill in an area the port is currently developing into a new container terminal.

The Port’s Middle Harbor Redevelopment Plan presents another opportunity for Los Angeles region contaminated sediments to be managed in accordance with the Contaminated Sediment Task Force’s guidance. This project includes construction of approximately 65 acres of new land for a marine container terminal, which will require approximately 2.5 million cubic yards of fill material (dredged sediments) in excess of the amounts to be generated by other elements of the project.

Between March 2012 and July 2012, approximately 1,200,000 cubic yards of material was imported into the Middle Harbor Fill Site for beneficial use. This included almost 800,000 cubic yards of third party material and more than 500,000 cubic yards of material generated from the Middle Harbor project.

Individual projects placed in the fill include:

- Marina del Rey Channel: 475,000 cubic yards (LA Beaches and Harbors, The Dutra Group)
- Rhine Channel: 85,000 cubic yards (City of Newport Beach, The Dutra Group)
- Lower Newport Bay Channel: 130,000 cubic yards (City of Newport Beach, RE Staite)
- Colorado Lagoon: 80,000 cubic yards (City of Long Beach, AIS Construction)
- Alamitos Marina: 42,000 cubic yards (City of Long Beach, The Dutra Group)
- Harborlight Marina: 6,000 cubic yards (City of Long Beach, The Dutra Group)
- Los Angeles River Estuary: 100,000 cubic yards (USACE, Manson)
- Rainbow Harbor: 75,000 cubic yards (City of Long Beach, The Dutra Group)

The Middle Harbor Fill Site was successful in providing a greater than 90 percent beneficial reuse rate for all dredge material produced in the Los Angeles and Orange County region for the past two years. This is very important to the State of California and federal resource and regulatory agencies as they have developed a long-term goal for achieving 100 percent beneficial use over the next 20 years. As of 2015, the first phase of the project was complete.

**Cost:** The Middle Harbor project is expected to cost $750 million and consolidate two older facilities into one efficient, 345-acre rectangular terminal. Construction will occur in multiple stages over a 10-year period.

**Socio-Economic Issues:** The Middle Harbor project provided the local government agencies and USACE with a lower cost disposal alternative for contaminated materials that would otherwise have been economically
impractical to dispose. The Port was essentially able to increase their property size for the cost of the sediment placement and landfill capping.

References:


**SANDAG Project I and II**

**Issue: Regional Beach Sand Project I and II—SANDAG’s regional sand management approach**

**Background:** Erosion has been a naturally occurring process at many of San Diego County’s beaches. Historically, beach sand lost to coastal erosion had been replaced, in large part, by inland sand deposited by natural riverine sedimentation processes and bluff erosion. However, these processes have been disrupted by a combination of coastal alterations and inland development (e.g., breakwaters, groins, jetties, and upstream dams). In addition, seawalls have reduced the volume of sand entering the nearshore environment from coastal bluffs. In response, the San Diego Association of Governments (SANDAG) designed and implemented a project in 2001 to nourish eroding beaches. This effort, known as the Regional Beach Sand Project I, dredged 2.1 million cubic yards of offshore sand for restoration of 12 beaches.

From September to December 2012, the Regional Beach Sand Project II placed 1.5 million cubic yards of sand on eight beaches in the cities of Oceanside, Carlsbad, Encinitas (Figure 49), Solana Beach, and Imperial Beach. In all, the project placed sand on approximately 19,000 feet of beach, or approximately 3.6 miles of coastline. The $28.5 million sand replenishment project was the result of a multi-agency effort coordinated by SANDAG. Funding came from the California Department of Boating and Waterways, as well as from the cities of Carlsbad, Encinitas, Imperial Beach, Oceanside, and Solana Beach. The goals associated with sand placement are to restore and maintain

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Figure 49: Site of placement of contaminated sediment for beneficial use at Port of Long Beach Middle Harbor Project.
coastal beaches, sustain recreation and tourism, enhance public safety, restore coastal sandy habitats, and reduce the proliferation of protective shoreline structures (e.g., harbors and jetties). The beach width gains from the 2001 beach nourishment project remained for an average of approximately four years and volumes of sand remained for an average of approximately six years. There still appeared to be some sand from the first project in the system; that material served as a foundation for the 2012 project.

**Cost:** Approximately $20 million for Regional Beach Sand Project I and $28.5 million for Regional Beach Sand Project II.

**Socio-Cultural Issues:** This case is an example of regional sediment management that: examined beach nourishment needs from a regional (rather than individual beach) perspective; allowed for priorities to be set and longer-term investments made; realized economies of scale; and promoted stakeholder buy-in through a deliberative planning process. Negative environmental impacts are thought to be few, and controversy about the project is limited. Many recreational and tourism-associated activities and ecological habitats have benefited from more expansive beaches. In addition, many view SANDAG as being proactive in outreach and engagement with communities and interested groups. Nonetheless, some concerns have been raised, including that some surfers worried about the impact to surf breaks, but many surfers were supportive. Community-specific issues typically involved potential noise and visual impacts. Some Del Mar residents were concerned that a disproportionate amount of sand for the project would come from its offshore areas. In most cases, these issues were ameliorated through outreach or by slightly modifying the project.

**Figure 50.** Regional Sand Replacement Project II—Nourishment at Encinitas.
*Source: SANDAG*

**References:**


Surfing and Shoreline Armoring

**Issue: Impacts of shoreline armoring on the surfing experience, and economic impacts.**

**Background:** There is little scientific understanding or baseline information on the effects of shoreline armoring on wave quality and the overall quality of surfing. Anecdotal evidence points to shoreline armoring having negative effects on surfing in three ways: loss of lateral access (e.g., no sand in front of a seawall); backwash off of seawalls; and alternation of coastal processes that form wave breaking sand bars. There are certainly locations where surfing breaks have been lost because of coastal construction or deconstruction (e.g., Oil Piers and Dana Point Harbor). Other coastal protection structures such as jetties are known to provide enhanced surfing in some locations. Some of the best breaks on the Pacific Northwest Coast are next to large jetties that stabilize entrances to harbors and estuaries. In some places (e.g., Yaquina Bay, Oregon and Humboldt Bay, California), there is good surfing between the jetties, especially when the open-ocean waves are too rough for most surfers. A good reference for how a wide variety of beach goers (including surfers) view coastal structures can be found in Kinsman, N. and Griggs, G.B. (2010).

Anecdotally, there appear to be impacts to surfers from shoreline armoring. There is little economic information on surfers that would allow for an evaluation of the economic impacts of such structures on surfing. Recently, there has been growing interest in the area of valuing specialized beach recreation. For example, a study conducted at Trestles Beach demonstrated that surfers had distinct patterns compared to other recreational beach users (Nelsen et al. 2007). Additionally, a 2009 study conducted in Solana Beach showed that surfing and other water sports were the number one activity at the beach, being enjoyed by more than 25 percent of beach visitors surveyed (Figure 51).
Figure 51. Solana Beach survey of beach goers.  
Source: CIC Research 2009

**Costs:** The loss of revenue from surfers is only beginning to be explored. Wagner et al. (2011) found that surfers are highly mobile, have many site choices, and that a surfer’s recreational beach visit to Southern and Central California counties contributes between $54 and $70 in local spending per visit. These expenditures per visit appear higher than what would be anticipated for the typical surfing day; they do not necessarily correspond to seemingly normal patterns of surfers going to the beach with “snacks and boards” and not stopping at local stores. The data are from actual experiences by surfers that responded to the Surfrider opt-in survey.

**Socio-Economic Issues:** The reduction in beach use or impaired surf conditions caused by armoring will require continued study, especially in light of recent findings that support surfers as unique users who are growing in numbers and who are finding increasing influence as a stakeholder group. The Surfrider Foundation has become a highly visible and effective advocate for surfers that oppose hard shoreline armoring approaches and support managed retreat in response to erosion. It played a significant role in the eventual selection of a retreat strategy at Surfer’s Point, Ventura, and continues to advocate for “softer” erosion responses along the California Coast.

**References:**


8. FINDINGS AND CONCLUSIONS

The California shoreline has been eroding for millennia. The extent of erosion is evident by the width of the continental shelf. The natural erosion and accretion process provided California with healthy beaches, most of which were naturally narrow along coastal bluffs and cliffs, and with vibrant marshes and wetlands. Rivers and eroding cliffs and bluffs, which retreated unimpeded over time, delivered sediment of all sizes to the shoreline.

The California shoreline continues to erode, but human intervention has changed the natural processes. The natural supply of sediment has been reduced through armoring of cliffs and bluffs, and constructing dams on rivers that would normally carry sediment to the coastline. Rivers were channelized and some were concreted, altering sediment flows. Navigation channels unintentionally serve as major sediment traps. Engineered beach and harbor protection structures were built, and many beaches were widened to meet the demands of beach goers.

Scientists find that about 40 percent of California’s beaches eroded during the early to late 1900s increasing to 66 percent over the past 25 years. Relatively natural beaches have eroded little, while beaches influenced by hard and soft engineering projects have experienced large changes. This conclusion is especially applicable to beaches in Southern California. While the common perception is that beaches are eroding, most beaches unaffected by such structures as groins or breakwaters appear to be fairly healthy when evaluated over long time frames (e.g., decades). The wide beaches that have been created by nourishment and stabilized by structures will, in time, retreat with reduced rates of nourishment.

Since the 1930s, some 1.3 million cubic yards of sand has been used annually to widen naturally narrow beaches in Southern California, but rates of nourishment have decreased over the past 20 to 30 years. These beaches face net sand losses over the coming decades without continuing nourishment and stabilization efforts. In addition, 10 percent of the State’s shoreline is armored, and most of that shoreline is experiencing passive erosion (i.e., narrowing beaches). At risk are billions of dollars in real estate and commercial properties, roads and railroads, the tourism industry, commercial and recreational fishing, and the loss of habitat for fish and wildlife.

This report provides an assessment of the economic and environmental implications of erosion of the California shoreline, as well as a summary of management responses to address these issues at federal, state, and local levels. The findings include:

1. Rates of erosion
   - The net erosion rate for the past 50 to 60 years was an average of -0.7±1.3 feet per year. The highest accretion rates were in Northern California and the highest erosion rates were in Southern California.
   - In general, coastal cliffs and bluffs are eroding approximately one foot per year. At some sites, erosion is negligible while at others, the unconsolidated cliff materials are eroding at 5 to 10 feet per year.
2. Sand and sediment supply

- Rivers have supplied 70 to 90 percent of beach sand, but damming of rivers has reduced that amount by 25 percent, a loss of approximately 2,500,000 cubic yards per year, mostly in the central and southern regions.
- Sand contributions from coastal cliffs and bluffs to littoral cells and beaches vary greatly along the shoreline. Armoring has reduced sand supply by an average of 11 percent with some areas experiencing 50 to 80 percent reductions.
- Beach nourishment has added 1,300,000 cubic yards per year on average to the overall sand budget for California’s major littoral cells, all of this in the Southern Region. There, beach nourishment represents 31 percent of the sand supplied to the beaches.

3. Sea level rise

The California coastline is eroding, and sea level rise will likely accelerate that process with enormous implications for local and state-wide economies, infrastructure, existing residential and commercial development beaches and dunes, flood control, marshes, mudflats, wetlands, and estuarine health.

- In the past 6 to 10 decades, tide gauges show that sea level increased south of Cape Mendocino and have generally decreased north of Cape Mendocino. An exception to decreasing sea levels is North Spit near Eureka.
- Over the next 9 decades, sea levels will rise both south and north of Cape Mendocino, although somewhat less to the north. Expected changes in sea level are:
  - By 2030 (relative to 2000):
    - South of Cape Mendocino: 4 to 30 centimeters (cm) (1.5 inches to 1 foot)
    - North of Cape Mendocino: -4 to 23 cm (-1.5 inches to 9 inches)
  - By 2050:
    - South of Cape Mendocino: 12 to 61 cm (5 inches to 2 feet)
    - North of Cape Mendocino: -3 to 48 cm (-1 inch to 19 inches)
  - By 2100:
    - South of Cape Mendocino: 42 to 167 cm (17 inches to 5.5 feet)
    - North of Cape Mendocino: 10 to 143 cm (4 inches to 4.7 feet)

Sea level rise will accelerate the erosion of cliffs and bluffs. Shoreline planners designed existing armoring of cliffs and bluffs for certain wave heights and wave energies. In the future, scientists expect wave heights to increase with increasing sea level rise, eventually inundating those armoring systems during large storms. If left unmanaged, beaches will migrate inland only if cliffs and bluffs are unconsolidated and can migrate inland as well. The human response will be to enhance the armoring to meet new sea level conditions, or to accept retreat and loss of the cliffs and bluffs. Without nourishment, areas that have been armored will experience erosion and beaches will eventually disappear; passive erosion will become an increasingly important issue. Without an adequate supply of sediment, beaches and dunes will provide little protection to cliffs and bluffs from increased height and energy of waves.

- In the central and northern regions, scientists project that the California coast will lose 81 square kilometers (km) (31 square miles) of land by 2100 relative to 2000 for 1 meter of sea level rise and 99 square km (38 square miles) of land for 1.4 meter of sea level rise.
• Estimates of the effects of erosion from sea level rise show that cliffs will erode an average distance of 66 meters (216 feet) by 2100, and dunes will erode an average of about 170 meters (558 feet) by 2100.
• 110 miles of railroad, 58 miles of highway, and 180 miles of roads are vulnerable to a 1.4-meter rise in sea level.
• Approximately 10,000 parcels, with an economic value estimated at $14 billion, are within the expected erosion zone.

Note: The estimates do not take into account any management responses to sea level rise, such as armoring, and the majority of the Southern California coast was excluded because of the number of ongoing initiatives on climate change and coastal hazards mapping. Mapping (i.e., identifying locations) in Southern California will likely lead to the installation of new armoring and strengthening of existing armoring, given the economic value of the infrastructure and industries at risk.

Marshes, mudflats, and wetlands are at serious risk because to survive the higher level of the sea in 2100, they must be able to migrate inland or grow upward through an adequate sediment supply. Marshes and wetlands provide protection from storm surges and flooding and without sediment, those protections may be lost. Entrapment of sediment behind dams, as well as the loss of sediment from erosion of cliffs and bluffs because of armoring, puts marshes and wetlands that cannot migrate inland at serious risk.

4. Social and economic impacts

California’s shorelines are a critical resource to the State’s economic and social wellbeing. Residents and tourists flock to beaches for recreation (e.g., surfing, jogging, birding, and swimming) and numerous businesses depend on resources accessible from the shoreline (e.g., fishing, boating, mineral extraction, and shipping). These recreational and commercial uses generate substantial revenues for local communities and the State (e.g., over $44 billion in 2013). Social impacts occur when societal benefits are directly affected by erosion, such as loss of beach quality (e.g., area, sand quality, and wave quality) and associated recreational uses, loss of private property, and damage to public infrastructure.

• This study found that the methods using hard structure approaches undertaken to control shoreline change often create both positive and negative social and economic impacts.

The negative impacts of armoring include the following:
  o Blocked or reduced public beach access;
  o Passive beach erosion and reduction in beach width, and associated beach recreational use;
  o Possible impacts on surfing and wave breaks;
  o Reduction in the amount of sand in the littoral drift for natural beach nourishment downdrift of the armored shoreline; and
  o Negative visual and aesthetic impacts (e.g., rip-rap).

The positive impacts of armoring include:
  o Protection of property from erosion;
  o Visual improvements to coastal views (e.g., East Cliff Drive); and
  o Sufficient public access to the beach.
Jetties, breakwaters, and groins have positive and negative impacts including:
- Lessen erosion on the targeted beaches, but cause erosion on down drift beaches; and
- Sometimes enhance surfing experiences down surf from jetties

- Quantification of costs attributable to shoreline erosion control, specifically beach nourishment and, to a lesser extent, shoreline armoring, were the two primary economic impacts of shoreline change examined in this report, and the two most common responses in the State of California.
  - Costs of shoreline hard armoring (borne by private property owners, local, state and federal governments): With just over 10 percent of California’s coastline armored (136 miles of seawalls), a rough estimate of construction costs for that armoring falls somewhere in the range of approximately $350 million to $7 billion, not including reconstruction and maintenance costs or the costs of secondary impacts.
  - Costs of nourishment (borne by local, regional, state, and federal governments): From 1984 to 2010, government agencies spent more than $67 million to nourish California beaches according to the California Department of Boating and Waterways (2011). The USACE expended $48 million on nourishment projects since 1990 (Los Angeles and San Francisco Districts 2012) for estimated total beach nourishment cost in the State of at least $115 million since 1984.

5. Environmental implications

The California coastal environment contains diverse habitats, including wetlands, estuaries, kelp forests, seagrass beds, mudflats, cliffs, sandy beaches, and dunes. These areas provide important habitat to a variety of plant and animal life. USACE describes the effects of erosion and accretion in this report but they are not quantified, due to the dynamic and complex conditions along the coastline, associated habitat, and biological resources.

Sediment from erosion can have both beneficial and undesirable impacts. Sediment is an important resource to maintain and restore beaches and coastal habitats, such as marshes, wetlands, and mudflats. However:

- Too much sediment can damage habitats, interfere with the food chain, and cause obstructed channels, overflowing rivers, smothered reefs, and high turbidity that blocks sunlight; and
- Too little sediment can lead to disappearing beaches and other eroded coastal features such as salt water marshes, with significant implications for aquatic and terrestrial habitat for a wide variety of species, potentially reducing the abundance and biodiversity of such animals as fish, turtles, and birds.

Wetlands and salt marshes can be quite resilient and adapt to changing conditions. An adequate supply of sediment is key to conserving these habitats. Wetlands and salt water marshes provide an array of ecosystems services contributing to the economy and social well-being. Well known functions of wetlands that can be impacted by erosion and accretion include:

- Commercial and sport fishery nurseries;
- Bird migratory resting, breeding, feeding, and cover;
• Filters for nutrients and control of sediments;
• Flood mitigation. Wetlands temporarily store floodwaters, releasing the water slowly into the system reducing flood peaks and surges;
• Recreational opportunities, including fishing and hunting;
• Potential for educational opportunities, serving as outdoor classrooms;
• The beauty and opportunities to experience nature; and
• Enhance the value of adjacent properties.

Erosion and accretion are associated with elevated levels of suspended sediment in the water and an increased amount of sediment settling on the seafloor.

• Excessive turbidity, caused by fine-grained sediments and colloidal materials, degrades water quality and increases morbidity among marine life. Higher turbidity increases water temperatures as suspended particles absorb heat, as well as reduces the concentration of dissolved oxygen. Increased turbidity also reduces the amount of light penetrating the water, which reduces photosynthesis and can have harmful impacts on estuaries, wetlands, kelp forests, eelgrass, and surfgrass.

• Increased sedimentation can blanket the sea floor and smother fish eggs. When the particles settle, they can smother bottom-dwelling benthic invertebrates. Non-burrowing substrate organisms, submerged aquatic vegetation, shell reefs (oysters) may be hardy enough to withstand some level of sedimentation, but if they are impaired, the recovery time is long and populations difficult to re-establish.

The management response to erosion and accretion can have unintended negative environmental consequences. For example, beach nourishment projects will impact biota on the beach or in the sand borrow area. These impacts include short term disturbance of the indigenous biota and forage base for fish and shorebird on the beach (e.g., by smothering with new sand or with incompatible material); impacts to the food web (potential to alter habitats or adjacent areas used by species for nesting, nursing, and breeding); and impacts to the biota in the sand borrow area from physical disturbance, turbidity, or settlement of suspended sediments. The recovery is generally in a year or less, especially when sand is placed on sand-starved beaches with limited habitat functions.
6. Governance and sediment management

To tackle the current and future erosion and sediment issues along the California shoreline, a Sediment Master Plan is under development by the CSMW. CSMW envisions the latest Sediment Master Plan to be a 10 to 15-year process to identify information needs, challenges, and actions needed to systematically approach sediment management along the coastline. The Sediment Master Plan is updated every two years, the most recent in 2012, and includes a compilation of tools, outreach actions, strategies, and informational reports designed to assist and guide sediment managers and others in systematically implementing sediment management throughout the California coast.

- Federal, state, and local entities are making significant progress in developing and assessing sediment transport; reconciling inconsistent regulations and policies; and addressing local economic, social, and environmental issues associated with sediment management and coastal erosion.
- The CSMW has produced a number of critical informational documents, computer-based tools, and outreach.
- In addition, local and regional agencies completed sediment management plans for specific coastline areas in Southern Monterey Bay, Santa Barbara and Ventura Counties, and San Diego County. Others are in progress. Preparation for implementation is underway with first steps including the development of programmatic environmental impact assessments.

Many of the federal, state, and local existing policies, procedures, and regulations developed over the past 50+ years need to be updated to consider the serious economic, social, and environmental implications of current and future erosion rates. The CSMW is in the process of reviewing existing policies, procedures, and regulations.

- One significant area that needs to be addressed is that increased sediment is needed to alleviate erosion of coastal marshes and wetlands that cannot migrate inland because damming of rivers has caused a loss of 25 percent (50 to 100 percent in the Southern Region) of sediment reaching the coast, and armorining has resulted in an average loss of 11 percent.
- Other reviews have been conducted identifying specific changes in policies and regulations by such organizations as the FEMA (FEMA 2000). Griggs, Patsch, and Savoy addressed the needs for change in “Living with the Changing California Coastline” (Griggs et al. 2006). Included among those recommendations are: strengthen the “line in the sand” against new shoreline structures, clarify geotechnical analysis requirements regarding development along the shoreline, and strengthen restrictions on the redevelopment of structures.

The recommendations considered by the CSMW, FEMA, and Griggs et al. are a start in addressing the needed policy discussions and the tensions between the private sector and the public sector regarding living, developing, and working on the eroding California coastline.
APPENDICES

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**APPENDIX A: ACRONYMS**

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<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>AMBAG</td>
<td>Association of Monterey Bay Area Governments</td>
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<td>BEACON</td>
<td>Beach Erosion Authority for Clean Oceans and Nourishment</td>
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<td>BCDC</td>
<td>San Francisco Bay Conservation and Development Commission</td>
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<td>CDFG</td>
<td>California Department of Fish and Game</td>
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<td>SWRCB</td>
<td>State Water Resources Control Board</td>
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<td>CSLC</td>
<td>California State Lands Commission</td>
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<td>CAP</td>
<td>Continuing Authorities Program</td>
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<td>CCC</td>
<td>California Coastal Commission</td>
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<td>CDBW</td>
<td>California Department of Parks and Recreation, Division of Boating and Waterways</td>
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<td>California Department of Fish and Wildlife</td>
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<td>CDPR</td>
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<td>CEQA</td>
<td>California Environmental Quality Act</td>
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<td>CGS</td>
<td>California Geological Survey</td>
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<td>CNRA</td>
<td>California Natural Resources Agency</td>
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<tr>
<td>CRSMP</td>
<td>Coastal Regional Sediment Management Plan</td>
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<td>CSMW</td>
<td>Coastal Sediment Management Workgroup</td>
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<td>EBM</td>
<td>Ecosystem based management</td>
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<td>EPA</td>
<td>Environmental Protection Agency</td>
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<td>ERDC</td>
<td>Engineer Research and Development Center</td>
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<td>FEMA</td>
<td>Federal Emergency Management Agency</td>
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<td>GDP</td>
<td>Gross Domestic Product</td>
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<td>GPS</td>
<td>Global Positioning System</td>
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<td>GIS</td>
<td>Global Information System</td>
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<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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<td>LCP</td>
<td>Local Coastal Plans</td>
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<td>LiDAR</td>
<td>Light Detection and Ranging</td>
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<td>LTMS</td>
<td>Long Term Management Strategy</td>
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<td>MND</td>
<td>Mitigated Negative Declaration</td>
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<td>NEPA</td>
<td>National Environmental Policy Act</td>
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<td>Abbreviation</td>
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<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
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<td>NSMS</td>
<td>National Shoreline Management Study</td>
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<td>PEIR</td>
<td>Programmatic Environmental Impact Report</td>
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<td>SANDAG</td>
<td>San Diego Association of Governments</td>
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<td>State Coastal Conservancy</td>
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<td>SPL</td>
<td>South Pacific Los Angeles District</td>
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<td>SPN</td>
<td>South Pacific San Francisco District</td>
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<td>TMDL</td>
<td>Total Maximum Daily Load</td>
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<td>USACE</td>
<td>U.S. Army Corps of Engineers</td>
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<td>USGS</td>
<td>U.S. Geological Survey</td>
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<td>WRDA</td>
<td>Water Resources Development Act</td>
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APPENDIX B: GLOSSARY OF TERMS

Accretion: May be either natural or artificial. Natural accretion is the buildup of land, solely by the action of the forces of nature, on a beach by deposition of water, or airborne material. Artificial accretion is a similar buildup of land by human activities, such as the accretion formed by a groin, breakwater, or beach fill deposited by mechanical means.

Aeolian: Pertaining to the wind, especially used with deposits such as loess and dune sand, and sedimentary structures like wind-formed ripple marks.

Armored shoreline: A section of shoreline that is characterized by hard engineering structures such as revetments, groins, breakwaters, or seawalls.

Backshore: That zone of the shore or beach lying between the foreshore and the coastline comprising the berm or berms, and acted upon by waves only during severe storms, especially when combined with exceptionally high water. This area may be reworked by aeolian action.

Barrier islands: A detached portion of a barrier beach between two inlets. It commonly has dunes, vegetated areas, and swampy terrains extending from the beach into the lagoon. Example: Outer Banks, North Carolina. These islands are typically created by longshore sediment transport that accretes sand to generate a sand spit extending from the shoreline.

Beach (or Shore): The zone of unconsolidated material that extends landward from the low water line to the place where there is marked change in material or physiographic form, or to the line of permanent vegetation (usually the effective limit of storm waves). The seaward limit of a beach, unless otherwise specified, is the mean low water line. A beach includes foreshore and backshore (Figure 52).

Breakwaters: A man-made structure protecting a shore area, harbor, anchorage, or basin from waves.

Climate change: Any significant measurable change in climate measures (e.g., precipitation, temperature, or wind) that lasts for an extended period.

Coastal Zone: The transition zone where the land meets water, the region that is directly influenced by marine and lacustrine hydrodynamic processes. Extends offshore to the continental shelf break and onshore to the first major change in topography above the reach of major storm waves. On barrier coasts, includes the bays and lagoons between the barrier island and the mainland.

Continental shelf: The region of the oceanic bottom that extends outward from the shoreline with an average slope of less than 1:100, to a line where the gradient begins to exceed 1:40.

Ecosystem-based management: An integrated, science-based approach to the management of natural resources that aims to sustain the health, resilience, and diversity of ecosystems while allowing for sustainable use by humans of the goods and services they provide.

Erosion: The removal of material by the action of natural forces. On a beach, erosion consists of the carrying away of beach material by wave action, tidal currents, littoral currents, or by deflation.

Estuary: (1) The part of a river that is affected by tides. (2) The region near a river mouth in which the fresh water of the river mixes with the salt water of the sea, and which received both fluvial and littoral sediment influx.

Figure 52. Definition of terms and features describing the coastal zone.  
*Source USACE Coastal Hydraulics Laboratory.*
Foreshore: The part of the shore, lying between the crest of the seaward berm (or upper limit of wave wash at high tide) and the ordinary low-water mark, that is ordinarily traversed by the uprush and backrush of the waves as the tides rise and fall.

Geomorphology: (1) That branch of physical geography which deals with the form of the Earth, the general configuration of its surface, and the distribution of the land and water. (2) The investigation of the history of geologic changes through the interpretation of topographic forms.

Groins: A shore protection structure built (usually perpendicular to the shoreline) to trap littoral drift or retard erosion of the shore.

Headland: A high, steep-faced promontory extending into the sea.

Littoral drift: The movement of sediment in the littoral zone as a result of currents and waves coming in at an angle to the shore (see also ‘longshore transport’).

Littoral transport: The movement of littoral drift in the littoral zone by waves and currents, which includes movement parallel (longshore transport) and perpendicular (on-offshore transport) to the shore.

Littoral zone: The area along the coastal profile where sediment can be transported by wave action. The landward limit is where normal wave action ceases and the seaward limit is where significant transport by wave action stops.

Longshore transport: The movements of littoral drift parallel to the shore by waves and currents.

Marine Terraces: Ancient marine shorelines or stand lines. They consist of a relatively flat wave-cut platform that is eroded by waves in the surf zone, and a cover of beach sand.

Mean high water: The average height of the high waters over a 19-year period.

Mean lower low water: The average height of the lower low waters over a 19-year period.

Mean tide level: A plane midway between mean high water and mean low water. Not necessarily equal to mean sea level. Also, half-tide level.

Nearshore zone: The portion of the beach profile extending from the limit of significant sediment transport by waves to the low tide line. The zone extends from the swash zone to the position marking the start of the offshore zone, typically at water depths in the order of 20 meters.

Offshore zone: The portion of the profile where there is no significant transport of sediment by wave action.

Overwash: The effect of waves overtopping a coastal defense, often carrying sediment landwards which is then lost to the beach system.

Regional sediment management (RSM): A systems-based approach for collaboratively addressing sediment resources within the context of regional strategies (estuarine, ocean) that address integrated sediment needs and opportunities.

Relative sea level rise: Change in elevation of the sea surface relative to a local land surface.

Revetments: A facing to protect an embankment or shore structure against erosion by wave action or currents.
Sediment: Solid material suspended in, or settled from, water. A collective term meaning an accumulation of soil, rock, and mineral particles transported or deposited from flowing water, wind, or ice.

Sea level: The average height of the surface of the sea for all stages of the tide over a 19-year period, usually determined from hourly height readings. It is also the average water level that would exist in the absence of tides.

Sea level rise: The long-term trend in mean sea level. The changes are due to causes such as glacial melting or formation, or thermal expansion or contraction of sea water.

Seawall: A structure, often concrete or stone, built along a portion of a coast to prevent erosion and other damage by wave action. Often it retains earth against its shoreward face.

Shoreline: Those areas of the coast where the impacts from the forces of waves, currents (those generated by waves/tides), tides, and storm surges are felt. It also can be defined as the intercept of the mean water level along the beach, or used loosely as the swash limit or landward edge of the backshore.

Submerged coastlines: Areas where the coast has sunk relative to sea level and the sea level has risen enough to inundate the lower parts of the landscape.

Surf zone: Zone of breaking waves along a coastline. The zone of wave action extending from the water line (which varies with tide, surge, set-up) out to the most seaward point of the zone (breaker zone) at which waves approaching the coastline commence breaking, typically in water depths of between 5 to 10 meters.

Terminal groin: A groin, often at the end of a littoral cell or at the updrift side of an inlet, intended to prevent sediment passage into the channel beyond.

Tidal inlet: An opening in a barrier island through which tidal flow occurs.

Washover fans: The fan-shaped accumulation of sediment on the landward side of a barrier island deposited by overtopping wave.
### APPENDIX C: HISTORICAL BEACH NOURISHMENT AND BYPASSING

**Table 1: Historical Beach Nourishment and Bypassing**

<table>
<thead>
<tr>
<th>Site</th>
<th>City/County</th>
<th>Date of project</th>
<th>Dredge/Fill Volume (yd³)</th>
<th>Funding</th>
<th>Activity</th>
<th>Source/Database</th>
<th>Sediment Source</th>
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<tbody>
<tr>
<td>West Newport Beach</td>
<td>Orange County</td>
<td>1933-35</td>
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<td>beach fill from Newport Bay</td>
<td>Source: CCSTWS-Orange County Region</td>
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<td>Source: Griggs and Savoy 1986; Hall 1952 DB: Tonya Clayton 1991</td>
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<td>Source: CCSTWS-LA Region (Draft Report, 2010)</td>
<td>Hyperior facility (construction in the coastal zone)</td>
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<td>beach fill from Mission Bay dredging</td>
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<td>1954</td>
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<td>Primary Source: Shaw, 1980 CCSTWS - San Diego Region</td>
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<td>Site</td>
<td>City/County</td>
<td>Date of project</td>
<td>Dredge/Fill Volume (yd³)</td>
<td>Funding</td>
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<td>Source/Database</td>
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<td>Ocean Beach</td>
<td>San Diego County</td>
<td>1955</td>
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<td>Mohammed Chang Dredging Database, May 29th, 2014</td>
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<td>Source: USACE-SPL (1970) CCSTWS Report</td>
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<td>Dredge/Fill Volume (yd³)</td>
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<td>Will Rogers State Beach</td>
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<td>Seal Beach</td>
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<td>River</td>
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<td>Surfside/Sunset Beach (Stage 1)</td>
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<td>Naval Weapons Station</td>
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<td>Source/Database</td>
<td>Sediment Source</td>
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<td>beach erosion control, groin and fill</td>
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<td>San Onofre</td>
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<td>Date of project</td>
<td>Dredge/Fill Volume (yd³)</td>
<td>Funding</td>
<td>Activity</td>
<td>Source/Database</td>
<td>Sediment Source</td>
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<td>River</td>
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<td>1967</td>
<td>150,000</td>
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<td>beach fill from Balboa Peninsula</td>
<td>Source: CCSTWS-Orange County Region</td>
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<td>Funding</td>
<td>Activity</td>
<td>Source/Database</td>
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<td>Source: CCSTWS-LA Region (Draft Report, 2010)</td>
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<td>Source: USACOE-LA 1969; 1986 (report) DB: Robert Wiegel 1994</td>
<td>Hyperion facility (construction in the coastal zone)</td>
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<td>Source: CCSTWS-LA Region (Draft Report, 2010)</td>
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<td>Source: CCSTWS-LA Region (Draft Report, 2010)</td>
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<td>Source: M. Chang, pers. Communication in report DB: Beach Nourishment Sediment Sources: Previous Studies and results from vibracoring field program, Orange County CA, Final Report, 1993</td>
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<td>nearshore placement from Santa Ana River (Federal Project?)</td>
<td>Source: CCSTWS-Orange County Region</td>
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<td>Date of project</td>
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<td>Source: CCSTWS-LA Region (Draft Report, 2010)</td>
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<td>Source: CCSTWS-Orange County Region</td>
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<td>Orange County</td>
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<td>backpassed from beach at east side of Santa Ana River to West Newport groin field</td>
<td>Source: CCSTWS-Orange County Region</td>
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<td>Dredge/Fill Volume (yd³)</td>
<td>Funding</td>
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<td>Source/Database</td>
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APPENDIX D: CALIFORNIA COASTAL LANDFORMS, HABITATS, AND BIOLOGICAL RESOURCES

The health of coastal waters depends on the conservation of a diversity of coastal habitats that provide shelter, food, breeding grounds, nursery areas, and migratory corridors for marine life, and that store water, buffer water quality, and resist storm related erosion (NRC 2005). Habitat changes can occur from an imbalance whereby sediment erodes and habitat disappears or, in some cases, sediment accretes excessively and alters the ecosystem (Berry et al. 2003). Various human activities including recreation, dredging, hardened protective structures (e.g., sea walls and bulkheads), runoff from agricultural practices, sewage from failed septic systems, and development have put increasing strain on coastal habitats over the years (Kalo 1990). Worldwide, habitat loss and its effect on biodiversity is a growing problem.

The following subsections summarize California’s coastal landforms and habitats.

Cliffs and bluffs

A specialized, diverse community of plants and animals has adapted to life on the challenging environment of cliffs and bluffs (Figure 53 and Figure 54). Prevalent ledges, gullies, slopes, and cracks provide areas where soil can collect allowing plants to grow. Sea figs and coyote brush grow on steep bluffs. Wildflowers such as poppies, irises, lupines, and introduced annual grasses and native fescues are found on these landforms (California Coastal Commission 1987). Forested bluffs provide habitat for a range of terrestrial animals, including nesting sites for birds and habitat for burrowing organisms (NRC 2007; Shaffer 2002). Bluffs that are unvegetated and rocky support a variety of birds (e.g., cliff swallows and peregrine falcons). Furthermore, tree and plant debris that has drifted and collected in the bluffs offers habitat for insects, amphipods, and other organisms. Mudflats adjacent to bluffs serve as habitat for mollusks, worms, birds, and crustaceans.

Figure 53. Cliffs and pocket beaches at Laguna Beach.
Source: Bill Ross/Corbis

16 A cliff is a vertical, or near vertical, rock exposure. A bluff is a steep promontory, bank, or cliff, presenting a broad face.
Marine Terraces

A marine terrace is the result of collisional tectonic coasts where uplift has taken place. Marine terraces are flat benches, usually less than a mile in width and commonly rise to elevations of 500 to 600 feet. Each terrace consists of a nearly horizontal or slightly seaward sloping surface backed by a steep or degraded sea cliff along its inland edge. Terraces were formed in the geologic past by sea erosion in the surf zone and then the surface was raised through tectonic movement (Figure 55).

Figure 55. Marine terrace formation. Wave-cut terraces on San Clemente Island, CA.

Note: Nearly horizontal surfaces, separated by step-like cliffs, were created during former intervals of high sea level; the highest terrace represents the oldest sea level high stand. Because San Clemente Island is slowly rising, terraces cut during an interglacial continue to rise with the island during the following glacial interval. When sea level rises during the next interglacial, a new wave-cut terrace is eroded below the previous interglacial terrace. Geologists can calculate the height of the former high sea levels by knowing the tectonic uplift rate of the island. Photograph by Dan Muhs, USGS. http://pubs.usgs.gov/fs/fs2-00/
Wind-generated waves break when they approach shore. The resulting landward directed surge of water can cause erosion, particularly on steep coastlines, because all the wave energy is concentrated in a narrow, intertidal zone. This usually results in a wave-cut notch at the base of cliffs, which periodically collapse, maintaining the steepness of the cliff. The result of continuous wave erosion at the base of cliffed coastlines is the formation of a wave-cut platform. Over time, the waves formed the vertical cliff face and the ocean smoothed the sea floor at the base of the cliff to form a flat step of the submerged terrace. If sea level falls or tectonic movement lifts the coastline, the wave-cut platform becomes a marine terrace. Several terrace levels are evidence of the mountain building process from between one and two million years ago wherein the oldest terraces at the top were uplifted by the same process that created the coastal mountain ranges. Where the slope of the coast is gentle, the wave energy is dissipated over a wider intertidal zone, creating lower energy conditions and allowing sediment to accumulate, forming a wide beach.

Marine terraces occur from San Diego to the Oregon border (Griggs 2010). The most wide-ranging terraces are located in Los Angeles County where a series of 13 terraces rise to 1,300 feet above sea level (California Coastal Commission 1987).

Marine terrace habitat usually comprises thin soil made of rock debris, marine fossil fragments, and shells left by waves on the once-submerged terrace. On top of this marine soil lies sand and gravel from streams and rivers crossing the terraces (California Coastal Commission 1987). While most plant life on marine terraces consists of grasses, in Northern California the terraces host redwood and pine forests. On the Mendocino coast, a unique forest of pygmy cypress and pine trees has adapted to the sandy, nutrient deficient soils on the upper marine terraces (California Coastal Commission 1987).

Coastal Sand Dunes

A coastal sand dune is an accumulation of sand grains on the beach that has been shaped into a mound or ridge by the wind. A dune forms with wind blowing dry sand landward and drifts accumulating around an object (e.g., plants and logs). Dune plants can help create a more stable landform (California Coastal Commission 1987; Dahm et al. 2005). Sources of sand to build dunes are offshore sandbars, sediment at the mouths of coastal rivers, and blowing beach sand (California Coastal Commission 1987). These natural formations are fragile and highly dynamic, shifting form when exposed to waves, wind, or human activity. Dams, coastal development, and other human activities contribute to dune degradation and destruction.

Along the northern California coast, dune fields are present as a series of parallel ridges perpendicular to the prevailing winds, called “transverse ridges” (California Coastal Commission 1987). In central California, there are U-shaped dunes with the concave side facing the prevailing wind. Of the 27 dune fields in coastal California, the largest are the Monterey Bay dunes, covering about 40 square miles, and the 18-square mile Nipomo Dune complex, north and south of the Santa Maria River. Other major dune fields are located at Humboldt Bay and San Diego Bay (California Coastal Commission 1987).

Dunes provide a natural protective barrier to inland areas from strong storm waves. A stable dune system can withstand some wave erosion without permanent damage (Figure 56). While California’s dunes are thousands of years old, current dune erosion is outpacing sand deposition (California Coastal Commission 1987).
Beaches

Beaches are dynamic landforms that can shift with wind and waves, accrete and erode. Often during winter, beach sand migrates offshore and develop sandbars. Beach sands return in the summer by the gentler waves to contribute to a wider beach than in the winter. Sediment from coastal rivers deposits 70 to 90 percent of beach sand. Longshore currents transport sand along the shore delivering “up to a million cubic yards of sediment annually to a single beach” (California Coastal Commission 1987). Littoral drift provides the longshore transport and movement of sand along the foreshore.

Figure 56. Ma’-el Dunes on the North Spit at Humboldt Bay.
Source: Jennifer Savage

Figure 57. Newport Beach, CA.
Source: Destination 360
Intertidal Rocky Shore

Rocky intertidal areas are found all along the California coast. These areas can be best viewed during low tide. Rocky intertidal habitats contain many suitable areas for sessile animals; animals that attach themselves to a solid object, such as oysters and mussels (California Coastal Commission 1987). Rock surfaces, crevices, and tide pools sustain a wide range of species. Rocky shores are highly resistant to erosion from waves and also offer some protection to inland areas (California Coastal Commission 1987).

Nearshore

The nearshore is an indefinite zone extending seaward from the shoreline well beyond the breaker zone to the position marking the start of the offshore zone, typically in water depths of the order of 20 meters. Many authors consider the nearshore to extend to the edge of the continental shelf, which in California is generally 15–30 kilometers wide (USACE 1995; Griggs 2010). On the California coast, this area is carved with submarine canyons, steep-sided valleys on the sea floor. Longshore currents transport sediment to the heads of submarine canyons where it flows out to the deep sea, reshaping the canyons as it flows (California Coastal Commission 1987).

The nearshore habitat varies depending on the coastal bathymetry. In general, these areas offer a nutrient rich, fertile environment for diverse animal and plant marine species (California Coastal Commission 1987). During the summer, phytoplankton blooms are the foundation for the ocean food web, feeding zooplankton (e.g., krill, jellyfish, protozoans, mollusk larvae, and arthropod larvae), which in turn are food for fish. The fish are eaten by marine birds and mammals (California Coastal Commission 1987). Nearshore waters also host kelp forests, which are rich growths of algae and home to an abundance of marine life.

Islands and Offshore Rocks
Off of the California coast, islands were created by geologic activity that occurred millions of years ago. These islands, as well as the numerous smaller islands, rocks, and sea stacks provide habitat for a range of marine plants, sea life (e.g., krill), birds, and marine mammals. For example, the Farallon Islands (Figure 59), a group of rocky islands and sea stacks 48 km west of the Golden Gate Bridge, are nesting grounds for more than half the California population of resident and migratory seabirds. The Channel Islands, in Southern California, are believed to be an extension of landward mountain ranges: the four northern islands related to the Santa Monica Mountains and the four southern islands believed to have been cut off from the Peninsular Ranges. Because the islands are cut off from the mainland, some have become unique environments where rare species have adapted (California Coastal Commission 1987).

![Farallon Islands](Figure 59. Farallon Islands. Source: Wayne and Judy Bayliff / SF Examiner)

Most offshore rocks, which are found on the North Coast of California, formed after waves cut away cliffs and left behind secluded groups of stronger rock. Like the intertidal rocky areas, these rocks have many crevices and ledges for attached animals and insects, and provide nesting areas for birds (California Coastal Commission 1987).

**Coastal Rivers and Streams**

Coastal rivers and streams carry important nutrients and sediment from upland areas to the coastal wetlands and estuaries at their mouths. The rivers and streams drop fine-grain sediment in the floodplains and are also a key component in replacing sand eroded from beaches. In Northern California, sediment is carried from the upper watersheds to coastal beaches during times of rainfall and runoff (Figure 60). This process occurs in Southern California only during large storms and floods. Human activity (e.g., dam construction and urban development) along the south coast rivers has reduced their natural sediment loads, which is a significant contributing factor in the erosion of the beaches (California Coastal Commission 1987).

The coastal rivers and streams in California are important to biologically diverse animal and plant populations. In particular, anadromous fish, such as salmon and steelhead, rely on these migratory paths to travel from the sea to fresh water to spawn; they also require well oxygenated streams, gravelly streambeds,
and spawning sites (California Coastal Commission 1987), characteristics that are affected by coastal erosion and accretion.

Figure 60. Mouth of Russian River.
Source: Andrew Alden, geology.about.com

Estuaries

Bays, lagoons, and sheltered coasts (hereinafter collectively referred to as estuaries) are coastal bodies of water that are surrounded by land on three sides (Kalo 1990). Estuaries form the transition zone between rivers and streams, and the open ocean. Because estuaries are confined by land, they are generally protected from waves, which allows plants to root, shellfish larvae to attach, and a variety of life to thrive (Kalo 1990). The shallow water of most estuaries allows light penetration to foster plant growth and deters ocean predators that avoid shallow waters (Kalo 1990). The system of water circulation with freshwater and salt water flow creates an optimal habitat for varied animal and plant species such as shellfish beds and submerged grasses (Kalo 1990).
Coastal Wetlands

In California, coastal wetlands are unique habitats that contain both aqueous and terrestrial characteristics. The majority of California's coastal wetlands are estuarine salt marshes with tidal channels and mudflats (California Coastal Commission 1987). When streams and rivers reach the sea, estuaries are formed, some with salt marshes and mudflats (Figure 61). Wetlands are home to a wide range of biologically diverse plants and animals, and are important areas for migrating birds (California Coastal Commission 1987). Serving as an important transition from land to sea, coastal wetlands provide nutrients and organic material to the ocean, and also serve as a nursing ground for many fish and other species. Further, wetlands help to mitigate the effects of storms, such as erosion, on inland areas and filter pollutants from failed septic systems or agricultural runoff (California Coastal Commission 1987).

Figure 61. Ormond Beach is home to a vast ecosystem of rich green wetlands and a unique coastline habitat.

Source: Kurt Preissler/Sierra Club California

As settlers moved to California, they built houses and farms on former wetlands resulting in a 90 percent reduction in wetland acreage since the gold rush of 1849 (California Natural Resources Agency 2010). According to the California Natural Resources Agency (2010), current estimates of coastal wetlands indicate that there are approximately 10,365 acres of intertidal beaches and rocky shoreline wetlands; 159,534 acres of saline and brackish estuarine wetlands. A good example is Morro Bay (Figure 62).
Kelp Forests

Kelp forests occur in nearshore waters along most of the California coast (Figure 63). These diverse growths of algae are composed of large brown algae (mostly “giant kelp”), smaller red and brown algae, and surf grasses, all anchored against waves and currents at the sea floor (California Coastal Commission 1987). Giant kelp is a fast-growing plant, that grows an average of 10+ inches per day during spring and reaches a height of over 250 feet (California Coastal Commission 1987). The leaves grow toward the surface and are held afloat by gas filled floats. Offering food and shelter, kelp forests are an important habitat for many species (California Coastal Commission 1987). An array of animals live on the rocky floor of the forest, including sea cucumber, sea star, abalone, anemone, and urchin. Invertebrates thrive in the kelp leaf blades and stems. A range of fish also lives among the beds, such as kelp bass, blacksmith, rockfish, and surperch. Finally, sea otters thrive in the canopy and eat the invertebrates, and harbor seals feed on fish in the kelp beds (California Coastal Commission 1987).
Found in the nearshore, intertidal, and subtidal zones throughout the State, surfgrass has leaves that are usually 1–4 millimeters wide, stems, and roots (Shaffer 2002; Wyllie-Echeverria, T., Hannan, S. Wyllie-Echeverria, and Shafer 2007). Surf grass beds provide food, shelter, and nurseries for fish and invertebrates. While the grass can recover from stem injuries, if an entire bed is destroyed, recovery is not reliable, and restoration projects have had mixed success (Wyllie-Echeverria et al. 2007).

**Eelgrass**

Eelgrass is an underwater flowering plant found throughout the entire coast of California and is another source of primary food production in the nearshore habitat (Shaffer 2002). While it grows completely underwater, it does require substantial sunlight to perform photosynthesis and therefore, prefers water less than 8 feet deep (CADFG 2008). Many species (e.g., scallops, crabs, fish, lobsters, and shellfish) rely on this plant for food, habitat, and nursery grounds. Eelgrass effectively filters excess nutrients that flow into coastal waters from agricultural and sewage runoff. Eelgrass also helps to reduce erosion by buffering the erosive power of currents (CADFG 2008). Eelgrass is protected as essential fish habitat, which sometimes complicates mitigation policies for sediment management in areas that have eelgrass.

**Biological Resources of the California Coast and Biological Effects of Erosion and Accretion**

For thousands of years, erosion and accretion have altered habitats and ecosystems. In today's terms, the environmental effects of erosion and accretion can be measured in terms of their impacts to ecosystem services. Ecosystem services are goods and processes such as food production, quality of life in coastal communities, commercial fisheries, and the recreational use of shorelines. Coastal goods include fish, fibers, seaweed, crabs, and sand. Coastal processes include the oceanic influence on weather, wave attenuation, removal of nutrients, contaminant sequestration, and maintenance of biodiversity (NRC 2007). Shoreline erosion, and sometimes accretion, leads directly to habitat change for marine mammals, fish, birds, invertebrates, and other animals that depend on those habitats. The net positive or negative effects of those changing services are site specific and need to be addressed over timeframes that capture major long-term influences such as the Pacific Decadal Oscillation.

**Invertebrates**

Invertebrates, which are far more numerous than vertebrates along the California coast, have evolved a wide variety of anatomical features, life cycles, and reproductive strategies. California invertebrates include urchins, sea slugs, squid, anemone, sea cucumber, shellfish or crustaceans (e.g., crabs, lobsters, and spiny lobsters), mollusks (e.g., scallops, abalones, and snails), corals, and worms. Invertebrates are a critical link in the coastal food chain, feeding on smaller sea life, insects, and plants, and provide food for marine mammals, sea birds, and humans.
A variety of invertebrates can be found from the sublittoral zone\textsuperscript{17} to the beach and dunes. In the intertidal zone, mollusks (e.g., razor and surf clams), crustaceans, and other invertebrates have adapted to wave action through burrowing or attaching themselves to hard structures such as rocks. At low tide, invertebrates can feed on the zooplankton in the sand particles and tide pools. Insects are also an important food source for invertebrates; kelp flies and a range of beetles are among the insects on the shore (California Coastal Commission 1987).

**Fish**

California’s nearshore environment is home to more than 450 species of finfish (CADFG 2001). The large universe of fish species in California can be grouped into four categories (Pacific Fishery Management Council 2010):

- Groundfish living on or near the bottom of the ocean, including over 90 species such as rockfish, flatfish (e.g., halibut), roundfish, sharks, and skates.
- Anadromous fish, such as salmon and steelhead, are difficult to manage because of their long migratory paths between fresh and salt water. The main California salmon species are coho and chinook (Figure 64).
- Coastal pelagic fish that live near the surface of the water, such as pacific sardine, chub mackerel, northern anchovy, market squid, bonito, yellowtail, barracuda, and white seabass (Figure 65).
- Highly migratory species, which are also pelagic living near the surface, including tuna, sharks, and swordfish.

While the hundreds of individual species cannot be adequately described in this report, there are several resources online for detailed information, such as the Guide to the Coastal Marine Fisheries of California\textsuperscript{18} and California Department of Fish and Wildlife’s Status of the Fisheries Report\textsuperscript{19}.

\textbf{Figure 64.} Salmon swim in Butte Creek in the Sacramento River system.  
\textit{Source: Kurt Rogers / SF Chronicle}

\textsuperscript{17} The sublittoral zone extends from below low tide to the edge of the continental shelf. This area can generally be found about 150 to 300 meters in depth. There is a great abundance of plant and animal life in this zone because the sunlight can reach the bottom in most areas, and nutrients are plentiful. [http://science124.tripod.com/id3.html](http://science124.tripod.com/id3.html).

\textsuperscript{18} Available at: [http://content.cdlib.org/view?docId=kt896nh2qd&query=&brand=calisphere](http://content.cdlib.org/view?docId=kt896nh2qd&query=&brand=calisphere)

\textsuperscript{19} Available at: [www.dfg.ca.gov/marine/status/](http://www.dfg.ca.gov/marine/status/)
Adding to the biological diversity of the California coast are several types of marine mammals that live and breed in the shallow waters, bays, rocky and sandy shore, and offshore islands. The broad categories of species present are dolphins, porpoises, sea lions, seals, and sea otters (Daugherty 1985) (Figure 66 and Figure 67). The main pinniped species, aquatic carnivores with streamlined bodies and limbs with flippers, are California sea lions, harbor seals, Steller sea lions, northern fur seals, and northern elephant seals. The most prevalent dolphin species in California are the Pacific white sided dolphin, northern right whale dolphin, striped dolphin, rough toothed dolphin, and Pacific bottlenose dolphin (Daugherty 1985).

In general, whales along the California coast live in deep water, but on their north and south migrations, gray whales are known to stay close to shore in shallow water, presumably for protection of the calves from great white sharks and orcas that prefer to attack from below. Monterey Submarine Canyon is a danger zone because the whales often cut across it rather than follow a shallow contour.
Offshore of Del Norte County, the seven-acre Castle Rock Island is an important Steller sea lion habitat (California Coastal Commission 1987). In the Channel Islands, San Miguel Island is home to five marine mammals: Steller sea lions, northern fur seals, California sea lions, harbor seals, and northern elephant seals (California Coastal Commission 1987). In San Mateo County, Año Nuevo Island has the largest Steller sea lion population in the State and a large population of northern elephant seals (California Coastal Commission 1987).

Figure 67. Piedras Blancas elephant seal beach.

*Source: Ian Parker*

**Sea Turtles**

The California coast is home to four of the world’s seven species of sea turtles: Olive Ridley, loggerhead, leatherback, and green. All four of these sea turtles are endangered or threatened under the Endangered Species Act. Sea turtles migrate long distances between California and Central America, Japan, Indonesia, and Mexico and require traditional feeding and nesting sites. Depending on the species, they feed on a variety of invertebrates, fish, and plants.

**Birds**

Along the California coast, a large number of resident and migratory birds are attracted to the plentiful and diverse food sources, as well as the nesting and shelter sites. In coastal wetlands, hundreds of thousands of birds migrate along the Pacific Flyway, and seek sanctuary and food in the salt and mud marshes. According to the California Coastal Commission (1987), “[d]uring the spring and fall months, coastal wetlands support flocks of waterfowl such as brant, pintails, mallard, and canvasbacks, and shorebirds such as sandpipers, curlews, willets, and godwits, which stop here to rest, feed, and in some cases, overwinter.” On California’s rocky shores and islands, sea birds nest and feed on fish and invertebrates during the spring breeding season (e.g., Figure 68). Other important island habitats include the small islands and offshore rocks between the Oregon border and Cape Mendocino in Humboldt County; the seven-acre Castle Rock Island is the State’s second largest seabird rookery (California Coastal Commission 1987).
Generally, California coastal birds fall into two groups: 1) birds that live nearshore, such as cormorants, pelicans, and most gulls; and 2) birds that only come to land during the breeding season, such as storm-petrels and alcids. Large numbers of non-nesting birds migrate through coastal California in the spring and fall, and many additional birds winter along the coast: shear-waters from as far away as New Zealand and Tasmania, many kinds of shore birds and waterfowl from arctic Alaska and Canada, pelicans and gulls from Mexico, and inland nesting birds such as grebes and small gulls. The major nesting colonies along the California Coast include storm-petrels: fork-tailed, leach’s, ashy, and black; the brown pelican; three species of cormorants: brandt’s, double-crested, and pelagic; the shorebird black oystercatcher; the western gull; alcids: common murre, pigeon guillemot, marbled murrelet, xantus’ murrelet, cassin’s auklet, rhinoceros auklet, and tufted puffin; and terns: caspian tern, forster’s tern, and elegant tern (Sowls et al. 1980). For nesting birds, coastal habitat is critical for reproduction and continuation of the species (Figure 69).
Terrestrial Animals

A variety of terrestrial animals are entwined in the marine food web. Fish predators include bald eagles. Predators of seabirds and shorebird include the peregrine falcon, white-rumped hawk, northern harrier, and white-tailed kite (Robinette et al. 2009). In sand dunes, a variety of animals such as gray foxes and striped skunks look for insects and dune plants to eat. Several species (e.g., deer mice, California voles, and black legless lizards) burrow into the sand to hide from raptor predators. Grazing mule deer eat shrubs on the dunes. In wetlands and coastal streams, many animals thrive on the abundant food sources, such as insects, frogs, salamanders, snakes, muskrats, beavers, and river otters (California Coastal Commission 1987).

Potential Environmental Effects of Erosion and Accretion for Each Region

Northern California

The rugged northern coast of California features an irregular shoreline with steep cliffs, bluffs, small offshore islands, and sea stacks (Hapke et al. 2006). In some areas, there is just a sliver of sand between the coastal mountains and the ocean and the shoreline is characterized by stretches of cliffs and small pocket beaches (Hapke et al. 2009). The area has a low human population and experiences severe storms, high rainfall, and high-energy waves. Many streams cut through the coastal cliffs, which deliver sediment to the coast. In several locations, sand spits create small embayments where coastal streams enter the ocean. In the stream valleys and bays, beaches are plentiful; the largest spit in the region extends across Humboldt Bay (Hapke et al. 2006). Areas with large dunes are located south of Smith River, north of headlands at Point Arena and Bodega Head, and at the entrance to Tomales Bay. Terraces south of Cape Mendocino and in the Cascadia Subduction zone are uplifting. Littoral transport may be interrupted where the heads of Mattole and Delgada Submarine Canyons extend into shallow water (Hapke et al. 2006).

This Region of the California coast is home to a variety of species. The marshes in Humboldt Bay and Eel River estuary contain Humboldt Bay owl’s clover and Point Reyes bird’s beak; Lyngbye’s sedge is found in marshes of Del Norte, Humboldt, and Mendocino counties (California Natural Resources Agency 2010). These plants are subject to erosion related habitat loss from development. Several anadromous salmonids live in the northern coast, including Chinook salmon, coho salmon, chum, steelhead, and cutthroat trout (California Natural Resources Agency 2010). Because of the migratory nature of salmonids and the dependence on established habitat and routes, changes in habitat and increased sedimentation along their traditional paths can have a negative impact. Other special northern coast fish species that either spawn or reside in nearshore coastal habitats throughout their lives, include the tidewater goby, green sturgeon, longfin smelt, and eulochan (California Natural Resources Agency 2010).

The northern coast provides extremely important habitat for the Marbled Murrelet, a seabird that nests solely in old growth conifer trees that are mostly within 15 miles of the coast (California Natural Resources Agency 2010). The majority of the State’s Marbled Murrelets also forage and overwinter in this region. While Brant birds are present along the entire coast, they are particularly tied to the eelgrass habitats in the northern coast (e.g., Humboldt Bay) as they feed almost exclusively on eelgrass (California Natural Resources Agency 2010).
Resources Agency 2010). Because Brant depend on eelgrass, the loss of eelgrass habitat from dredging, development, and other human activity has a negative impact on their numbers. Similarly, the tufted puffin used to inhabit the entire California coast but is now limited to the northern coast; alteration of breeding habitats is among the reasons for the reduction in breeding range (California Natural Resources Agency 2010).

Pinniped species that typically occur on the northern coast are the Steller sea lion, northern elephant seal, harbor seal, and California sea lion. Steller sea lion populations have been dropping (California Natural Resources Agency 2010).

Central California

The Central California coast is a diverse, transitional region that includes the wet climate and high wave energy of the Northern California coast and the dry climate and lower wave energy of the Southern California coast (Hapke et al. 2006). From marine terraces to coastal bluffs, high coastal slopes, large dune areas, coastal mountains and their basins, the central coastline is both unique and beautiful (Hapke et al. 2009). In some of the heavily developed areas, seawalls and revetments are used to address cliff erosion. Dams along the Santa Maria and Santa Ynez Rivers have reduced sediment delivery to the coast. Monterey, Carmel, and Partington Submarine Canyons may serve as sinks for beach sand migrating along the shore (Hapke et al. 2006). Point Reyes and the Farallon Islands are important breeding grounds for sea birds and are also major pinniped rookeries and haul out sites (California Coastal Commission 1987).

Commensurate with its wide range of habitats, including large estuaries and kelp forests, there is a great biological diversity on the central coast. The many shorebirds in this area include the western snowy plover, willet, whimbrel, long-billed curlew, marbled godwit, and American avocet (UC Davis Wildlife Health Center 2007). Anadromous and pelagic fish rely on the coastal estuaries, such as Elkhorn Slough and Morro Bay, for nursery habitat. The delta smelt and tidewater goby are endemic to the central coast (UC Davis 2007). A wide variety of invertebrates are also present. Pismo clams are an example of invertebrates endemic to this region (California Conservation Committee 1987; UC Davis 2007). The prevailing marine mammals along the central coast are the harbor porpoise, Dall’s porpoise, Pacific white-sided dolphin, Steller sea lion, California sea lion, Northern fur seal, Northern elephant seal, Harbor seal, and the sea otter (McChesney no date). The leatherback sea turtle also frequents areas along the central coast (McChesney no date).

Southern California

The Southern California coast, which is the most highly developed coastal region, has more urban coastal areas and lower energy waves than the north and central regions (Hapke et al. 2006). While wide sandy beaches are prevalent in many parts of the regions, in some stretches of the coast, such as parts of San Diego County, many beaches are narrow because of erosion (Hapke et al. 2009). Starting at Point Conception, the geology of the California coast begins to change because of the tectonic setting.

In the Santa Barbara area, there are narrow beaches and unique boulder deltas that are remnant flood deltas from mountain creeks. Downcoast from Santa Barbara near Ventura and Oxnard, the Ventura River
and the Santa Clara River are two river systems that remain in their natural states, not channelized by concrete and without dams on the main channels. Their drainage areas have abundant sand and gravel in the watersheds, and thus the rivers contribute to maintenance of the beaches, such as Ventura. Wide plains and sandy beaches are evident in Ventura, Santa Monica, Los Angeles, and Mission Bay. Mid-sized dune fields can be found near Oxnard and Silver Strand (Hapke et al. 2006).

Unique organisms live on the southern coast. With respect to coastal plants, salt marsh bird’s beak and Ventura marsh milk-vetch are special status species of the southern coast (California Natural Resources Agency 2009). The rockfish species bocaccio, cowcod, canary, and widow rockfishes have been identified for special protection (California Natural Resources Agency 2009). Other fish deemed to need special protection include garibaldi, steelhead trout, giant sea bass, abalone, California sheephead, white seabass, California halibut, kelp bass, barred sand bass, surf perch, and California grunion (California Natural Resources Agency 2009). White, pink, and green abalone live solely along the southern coast (California Natural Resources Agency 2009). Important south coast invertebrates include the California spiny lobster, warty sea cucumber, and kellet’s whelk (California Natural Resources Agency 2009). Four species of sea turtles occur off the southern coast: green, loggerhead, olive ridley, and leatherback (California Natural Resources Agency 2009). The southern coast is home to a range of sea and shore birds that have special status. The offshore islands and rocks provide excellent habitat for roosting, foraging, and forming breeding colonies. The Channel Islands, in particular, are an important habitat for birds, including ashy storm-petrel, black storm-petrel, California brown pelican, California least tern, double-crested cormorant, rhinoceros auklet, western snowy plover, and xantus’s murrelet (California Natural Resources Agency 2009). Other important bird species found in the southern coast are the American bald eagle, belding’s savannah sparrow, elegant tern, and osprey (California Natural Resources Agency 2009).

The southern coast hosts seven species of pinniped: Pacific harbor seals, California sea lions, northern elephant seals, Guadalupe fur seals, northern fur seals, Steller sea lions, and ribbon seals. The first three species are the most common and the latter four are rarely seen. The southern sea otter occasionally visits the southern coast but is more prevalent on the central coast. Cetacean species are well represented on the southern coast with over 33 species (California Natural Resources Agency 2009).
APPENDIX E: REFERENCES


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APPENDIX F: REFERENCES FOR ECONOMICS SECTION

Statewide Information


20 Full annotated bibliography available on request


Northern Region (Oregon Border to Tomales Point)


Central Region (Tomas Point to Point Buchon)


**Southern Region (Point Buchon to Mexico Border)**


References for Section 4:

Economic and Social Impacts of Erosion and Accretion21

STATEWIDE INFORMATION


21 Full annotated bibliography available on request


NORTHERN REGION (OREGON BORDER TO TOMALES POINT)


CENTRAL REGION (TOMALES POINT TO POINT BUCHON)


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**SOUTHERN REGION (POINT BUCHON TO MEXICO BORDER)**


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