FEMA AND STATE OF THE ART COASTAL EROSION
MAPPING ALONG THE SAN DIEGO COUNTY, CALIFORNIA SHORELINE

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ABSTRACT
The San Diego County shoreline, from San Mateo Point to the Mexican International Border, is an erosional coastline consisting of narrow beaches backed by steep seacliffs. The seacliffs of San Diego are cut into coastal marine terraces, range from 5 to 115 meters high, and are primarily composed of consolidated Late Cretaceous and Eocene sedimentary material overlain by unconsolidated Pleistocene terrace deposits.

Coastal erosion in San Diego County is episodic, site-specific, and a function of both marine and terrestrial processes. Both the beaches and seacliffs of San Diego County are subject to erosional processes including rising sea level, large storm waves, rainfall-induced mass wasting, grading of the bluff-top, alteration of natural drainage patterns, and solution of groundwater from the collapse of coastal cliff storm drains.

At the University of California, Santa Cruz (UCSC), high-resolution shoreline erosion rates have been determined for San Diego County using recent and historical aerial photographs and state-of-the-art shoreline mapping techniques. These rates were generated as part of a nation-wide study funded by the Federal Emergency Management Agency (FEMA) to determine how projected or potential economic losses from shoreline erosion might impact the resources of the National Flood Insurance Program (NFIP). Despite the high-resolution erosion rates utilized in the FEMA study, the objective of this study may be difficult to achieve due to the lack of detail and inaccuracies of the previously mapped Flood Insurance Rate Maps (FIRM's). However, the erosion rates generated at UCSC for FEMA are a valuable resource for coastal scientists and planners faced with making wise coastal land-use decisions in San Diego County.

INTRODUCTION
Long-term erosion rates are usually the key factor in evaluating and conditioning oceanfront development projects and permits. However until recently, technological limitations have hindered the accurate determination of seacliff erosion rates and rendered them unreliable. With significant advancements in shoreline mapping technology over the past few years, a $100,000+ state-of-the-art, softcopy photogrammetric coastal imaging lab was built at UCSC. This facility was funded by the National Science Foundation (NSF), FEMA, the Earth Sciences Board, the Institute of Marine Sciences, and the United States Geological Survey (USGS). As part of FEMA’s program to assess the feasibility and economics of adding erosion-prone ocean front property to the federal flood insurance program, high-resolution coastal erosion maps were created at UCSC for San Diego County, from the Mexican International Border to Oceanside Harbor.
This project (completed in October 1997) has provided an extremely valuable data set for coastal scientists, planners, and decisionmakers. It is particularly unique in that coastal erosion rates have never been determined so extensively (both temporally and geographically) with such high-precision shoreline mapping techniques.

SAN DIEGO COUNTY, CALIFORNIA
San Diego County has a population of approximately 2 million people living along 122 km of shoreline. The San Diego County shoreline (Figure 1), from San Mateo Point to the Mexican International Border, is an erosional coastline consisting primarily of narrow beaches backed by steep seacliffs which have been extensively urbanized. The seacliffs of San Diego are cut into raised coastal marine terraces, range from 5 to 115 meters in height, and are primarily composed of consolidated Eocene and Cretaceous sedimentary rocks overlain by unconsolidated terrace deposits.

*Figure 1 - San Diego County shoreline map (From Flick, 1994).*
Bluff and cliff erosion are an ongoing concern. As a result of heavy rains and large waves during the severe winter storms of 1983 and 1988, this county sustained $17.5 million in public and private coastal property and infrastructure damage. Kuhn and Osborne (1987) have shown that much of the seaciff erosion occurring in San Diego over the past 45 years has been a result of subaerial mass-wasting during above average rainfall events which rapidly saturate the seaciffs, providing optimal failure conditions. The majority of the rocks exposed in the San Diego County seaciffs are Eocene silstones, mudstones, shales, sandstones, and conglomerates capped by Pleistocene marine terrace deposits (Kennedy, 1975). Late Cretaceous sandstones, shales, and conglomerates are also present and are exposed in the seaciffs from the Point Loma Peninsula to La Jolla (Kennedy, 1975). In general, the seaciffs composed of older Cretaceous material are more resistant to erosion than those composed of Eocene material and as a result, account for the occurrence of headlands at both Point Loma and Point La Jolla.

The San Diego County shoreline can be divided into three littoral cells including the Oceanside, the Mission Bay, and the Silver Strand cells. Under natural conditions, sediment is supplied to San Diego beaches by rivers, streams, and seaciff erosion. In addition, large volumes of sand-sized material are artificially supplied to the beaches via public and private beach nourishment projects. Exerts (1991) has determined that the sediment supplied to San Diego County beaches may serve as an effective buffer against wave induced seaciff erosion and that the amount of sand supplied, both naturally and artificially, often determines the erosional susceptibility of the coastline.

SHORELINE EROSION REFERENCE FEATURES
In California, upon certification of "Local Coastal Programs (LCP's)" by the California Coastal Commission, individual local jurisdictions have the power to regulate shoreline land-use decisions. The majority of local coastal "setback" regulations refer to the shoreline reference feature as the landwardmost edge of the bluff-top or dune. In the case of an overhanging or oversteepened cliff edge, development setbacks may be based on a 30 degree line projected from the base of the cliff to the surface of the proposed development site.

For the purposes of the FEMA Erosion Hazards Study, and in order to obtain meaningful and accurate erosion rates, three different erosion reference features were mapped depending on the character of the shoreline and whether or not it had been altered by the presence of protection devices. Consistent with California state policies,
the landwardmost edge of the bluff top or cliff top (Figure 2) served as the primary erosion reference feature for San Diego County. In areas which are extensively developed and armored such that the cliff-top or bluff-top is not a feasible erosion reference feature, the landward edge of existing shoreline protection structures and development served as an alternate erosion reference feature. In other areas characterized by low-lying, unconsolidated dune and beach deposits (such as portions of the Coronado and Oneonta Slough areas), the erosion reference feature was the seaward edge of dune vegetation.

As a result of the episodic nature of coastal erosion, and because the shoreline is influenced by both marine and terrestrial processes which may operate on different time scales, erosion rate data determined using different erosion reference features should not be directly compared. The same caution applies when examining erosion rates which have been determined using sets of photographs which span different time periods. This is because over the short-term, cliffs may retreat at different rates depending on the
magnitude and type of erosive agents and whether or not the cliff is composed of homogeneous or heterogeneous material (Figure 3).

![Classification of coastal cliffs based on relative importance of marine vs. terrestrial erosion (adapted from Emery and Kuhn, 1982)](Image)

**CLASSIFICATION OF COASTAL CLIFFS**

**SAN DIEGO EROSION RATE METHODOLOGY**

Photography flown for the National Oceanic and Atmospheric Administration in 1994 at a scale of 1:24,000 served as base imagery for the study. This flight provided the only existing continuous coverage within the time frame required by FEMA. Aerial photographs taken in 1932, 1949, 1952, and 1956 and at scales of 1:9600, 1:20,000, 1:12,000, and 1:12,000 respectively, provided historical shoreline data. Although the use of four sets of historic aerial photographs was necessary, the majority of the San Diego coastline was covered by the 1932 and 1952 imagery (Table 1).

**SAN DIEGO COUNTY AERIAL PHOTOGRAPH DATA SETS**

- 1932 Oceanside, Encinitas, Solana Beach, Del Mar  
  (acquired from the Fairchild Collection)
- 1949 Coronado, Silver Strand, Imperial Beach  
  (acquired from National Archives)
- 1952 Torrey Pines, La Jolla, Pacific Beach, Mission Beach, Point Loma  
  (acquired from UCSB)
- 1956 Carlsbad  
  (acquired from UCSB)
- 1994 San Diego County  
  (acquired from UCSB)
To generate shoreline erosion rates for San Diego County, softcopy photogrammetry and geographic information system technologies were employed. The steps involved in the application of softcopy photogrammetry to the measurement of shoreline erosion rates (using aerial photographs) are summarized in Table 2. For a more detailed explanation of this methodology refer to Moore, Benumof, and Griggs (in preparation).

**THE SOFTCOPY PHOTOGRAMMETRY PROCESS**

1. Obtain digital imagery - historical and recent
2. Gather GPS control
3. Obtain camera reports
4. Perform aerial triangulation
5. Generate stereo pairs
6. Generate / Edit Digital Elevation Models
7. Generate orthophotographs
8. Digitize shoreline erosion reference features
9. Run erosion rate program
10. Generate maps

*Table 2: The softcopy photogrammetry process*

**SAN DIEGO COUNTY EROSION RATE RESULTS**
(Refer to Figures 1, 4, 5, and 6 for field locations and erosion rate summaries)

**Oceanside Area**

The northernmost or Oceanside reach of San Diego county is characterized by a moderately wide sandy beach backed by city park facilities and dense beach development. In addition, buildings have been terraced into or constructed on top of 5 to 13 meter high cliffs. Since the construction of the Oceanside Harbor jetties in 1942, downcoast beach erosion has been a problem and has been mitigated by sand bypassing, dredging, and beach nourishment (Ilerman and Jenkins, 1985). Over the past 55 years approximately 12 million cubic meters of sand have been placed on Oceanside City Beach (Flick, 1994). This section of shoreline has been heavily armored by a combination of protective structures including concrete seawalls and riprap which serve as the shoreline erosion reference feature. Flooding and wave-overtopping of armoring occurred at many sites during the winter storms of 1941, 1978, 1980, and 1983 (Kuhn and Shepard, 1984). As a result of the extensive beach nourishment and armoring of the Oceanside area, shoreline erosion rates are minimal and average 0 to 3 cm/year for the majority of the reach over the 62-year period from 1932 to 1994. However, average erosion rates at Oceanside Harbor, where the historical dune vegetation has eroded, range from 2 to 21 cm/year.

**Carlsbad Area**

The Carlsbad area may be divided into two sections consisting of Carlsbad State Beach and the area south of Carlsbad State Beach. The coastline at Carlsbad State Beach is characterized by a narrow, sand and cobble beach backed by 10 to 20 meter high cliffs composed of Eocene sandstone capped by Pleistocene terrace deposits. This section of
coast has been armored with concrete seawalls and riprap, however most shoreline protection was not emplaced until the late 1980’s. The Carlsbad seawall and promenade was constructed in 1988 to stabilize this portion of cliffs after it was severely eroded during the storms of the late 1970’s and early 1980’s (Flick, 1994). The shoreline erosion reference feature for this section is the landward edge of the cliff-top. Average erosion rates for the Carlsbad State Beach area range from 3 to 23 cm/year over the 62-year period from 1932 to 1994.

The South Carlsbad State Beach area is characterized by a narrow cobble and sand beach backed by 3 to 20 meter high cliffs. The cliffs of this area are composed of Eocene sandstone that have been severely eroded by wave action and sub-aerial mass-wasting. The erosion reference feature for this section is the landward edge of the cliff-top. Average erosion rates range from 3 to 58 cm/year over the 38-year period from 1956 to 1994.

Encinitas Area
The cliffs of the Encinitas area are composed of Eocene-aged units capped by poorly consolidated Pleistocene terrace deposits. Both units are generally susceptible to landsliding and human-induced erosion. The cliffs of the Encinitas area are also subject to wave erosion during above average high tides and storm periods as the beaches are generally very narrow. Shoreline protection in the Encinitas area is not continuous and varies widely in type of construction. The shoreline erosion reference feature for this section of coastline is the landward edge of the cliff-top. Average erosion rates for this section range from 2 to 29 cm/year over the 62-year period from 1932 to 1994.

Solana Beach Area
The Solana Beach stretch of coastline is characterized by a narrow, sandy beach backed by intensively developed approximately 20 meter high cliffs. The cliffs of this area are composed of Eocene sandstone overlain by unconsolidated Pleistocene terrace deposits. The Eocene material commonly fails along nearly vertical discontinuities resulting in cave collapse (Kuhn and Shepard, 1984). Shoreline armor in this area is sparse but consists of concrete seawalls and rip-rap. The shoreline erosion reference feature for the Solana Beach area is the landward edge of the cliff-top. Average erosion rates for this section range from 3 to 31 cm/year over the 62-year period from 1932 to 1994.
San Diego County Erosion Rates
(cm/yr)

![Graph showing erosion rates for different locations in San Diego County.]

**Figure 4. San Diego County FEMA Erosion Hazards Project erosion rates.**

**Del Mar Area**

The northern Del Mar area is characterized by a wide, low-lying, and popular sandy beach which offers protection to the dense residential development behind it. Several protective structures exist along this stretch including concrete seawalls, riprap, sheet-pile seawalls, and timber seawalls. The shoreline reference feature for the northern Del Mar area is the landward edge of shoreline armoring or the seaward edge of beach development as compared to the seaward margin of the 1932 vegetation line. Average erosion rates for this stretch range from 2 to 13 cm/year over the 62-year period from 1932 to 1994.

The southern Del Mar area consists of a narrow, sandy beach backed by nearly vertical, 15 to 30 meter high cliffs with a railroad bench cut into the face. The railroad was constructed in 1910 and has experienced numerous failures (Kuhn and Shepard, 1984). Pleistocene terrace deposits comprise the majority of the cliffs in this area, however, the bedrock consists of an Eocene sandy claystone. The shoreline erosion reference feature for the southern Del Mar area is the landward edge of the railroad cut. Little shoreline armoring exists along this stretch and average erosion rates for the area range from 2 to 34 cm/year over the 62-year period from 1932 to 1994.
San Diego County Erosion Rates
1932-1994 (cm/yr)

* The Del Mar average does not include the Del Mar Beach area
* The La Jolla average does not include the La Jolla Shores area

Figure 5. San Diego County FEMA Erosion Hazards Project erosion rates

Torrey Pines Area
The Torrey Pines area is characterized by a narrow- to medium-width sandy beach backed by low, active dunes and very high, steep, eroding cliffs, many of which have been developed. Cliffs in this area exceed 90 meters in height and are primarily composed of Eocene sandstone and shale. Subaerial mass wasting is the dominant erosive mechanism in this area and many landslides have occurred. In 1982, a 175 meter long section of the Torrey Pines cliffs failed and approximately 1.38 million cubic meters of material was deposited on the beach (Vanderhurst et al., 1982). In addition, the Torrey Pines area is void of shoreline armoring. The erosion reference feature for this reach is the landward edge of the cliff-top which is generally marked by a landslide scarp. Average erosion rates for the Torrey Pines area range from 2 to 55 cm/year over the 42-year period from 1952 to 1994.

La Jolla Area
The majority of the La Jolla area is characterized by rocky, wave-cut platforms, 5 to 20 meter high vertical cliffs, and pocket beaches. The cliffs are composed of Cretaceous sandstone interbedded with shale and are capped by poorly consolidated Pleistocene material. Approximately 25% of the cliffs are fronted with various types of shoreline protective structures (Flick, 1994). The shoreline erosion reference feature for the La Jolla area is primarily the landward edge of the cliff-top except at La Jolla Shores where a sandy beach of variable width is backed by a low armored cliff. The shoreline reference feature for the La Jolla Shores stretch is the continuous shoreline armoring occurring along this reach. Typical average erosion rates for the La Jolla area range from 0 to 17 cm/year over the 42-year period from 1952 to 1994.
Pacific Beach / Mission Beach Area

The northern section of the Pacific Beach shoreline is characterized by a moderately wide sandy beach backed by steep, 15 meter high, heavily-developed cliffs. The cliffs in this area are composed of Phocene sandstone and conglomerate capped by Pleistocene material. The cliffs along this reach are largely unprotected and the erosion shoreline reference feature is the landward edge of the cliff-top. Average erosion rates range from 2 to 24 cm/year over the 42-year period from 1952 to 1994.

The remainder of the Pacific Beach and Mission Beach shoreline is characterized by a low-lying beach of variable width backed by residential, public, and commercial development. This entire reach is protected by a concrete seawall which fronts a heavily utilized boardwalk and serves as the shoreline erosion reference feature. The concrete seawall was overtopped during the 1982, 1983, and 1988 storms (Armstrong and Flick, 1989), however no net shoreline erosion has occurred over the 42-year period from 1952 to 1994.

Point Loma Area

The Point Loma area is characterized by pocket beaches, wave-cut platforms, and high, steep cliffs. Many sea caves have formed in the cliffs along this reach as a result of undercutting by waves. The cliffs are composed of Cretaceous shale interbedded with sandstone and capped by poorly consolidated Pleistocene material. Many different types of shoreline protection structures occur along this stretch, however their occurrence is discontinuous and site-specific. The shoreline reference feature for the Point Loma area is the landward edge of the cliff-top and average erosion rates range from 2 to 26 cm/year over the 42-year period from 1952 to 1994.

Coronado / Imperial Beach Area

The Coronado area is a section of coastline that has been highly altered by human efforts but is relatively stable as a result of past beach nourishment projects and beach stabilization structures. The area is characterized by a wide, sandy beach backed by shoreline protective structures and is defined by two shoreline erosion reference features. At Sunset Park, the shoreline consists of low, active dunes and the seaward edge of dune vegetation serves as the erosion reference feature. A riprap revetment and associated development serves as the shoreline erosion reference feature for the remainder of the Coronado reach. In 1904, the Coronado area was stabilized by the construction of the 2,200 meter long Zuniga Jetty to the north (Shaw, 1980). Between 1946 and 1990 approximately 35 million cubic meters of sand from San Diego harbor was deposited on the beaches of Coronado and the Silver Strand section to the south (Flick, 1994). As a result, no shoreline erosion has occurred; in fact, at Sunset Park the shoreline has accreted as much as 97 meters over the 45-year period from 1949 to 1994.

The Imperial Beach area is characterized by a narrow sandy beach backed by dense residential and commercial development. The Imperial Beach area has been subject to beach erosion for many years (Flick, 1994); however, like Coronado to the north, it has been somewhat stabilized by shoreline protective structures and beach nourishment. The shoreline erosion reference features for this reach are the shoreline protective structures and associated beach development in the City of Imperial Beach and the seaward edge of dune vegetation at Oneonta Slough to the south. Over the 45-year period from 1949 to 1994, no shoreline erosion has occurred along the Imperial Beach stretch as a result of
shoreline armoring and beach nourishment. However, as much as 13 meters of shoreline retreat has occurred along the undeveloped reach at Oneonta Slough.

San Diego County Erosion Rates
1949-1994 (cm/yr)

![San Diego County Erosion Rates Graph](image)

Figure 6. San Diego County FEMA Erosion Hazards Project erosion rates

**Discussion**

The stability of San Diego seacliffs (and probably many other rocky coastlines as well), in response to the forces of marine and terrestrial erosion, is dependent primarily on the physical properties of the material (lithology and structure). Coastal geologic and geomorphic literature contains many references to rock strength and its implications for erosional landform development, but few (if any) measurements or quantitative assessments of material strength (Selhy, 1982). As a result, coastal geologists concerned with documenting and interpreting coastal erosion rates have been limited in their ability to quantitatively evaluate the factors responsible for these rates.

A quantitative investigation of the relationship between long-term coastal erosion rates, marine and terrestrial erosive processes, and the lithological/structural properties of the eroded rocks themselves, is the next step to understand the quantitative significance of the factors which control recession of the San Diego coastline. The objective of current research is to determine why certain rock masses are stronger or more resistant to erosion than others. Results of detailed field and laboratory investigations of overall rock strength of the cliff-forming materials will be integrated with the high quality erosion rate data set provided by the San Diego FEMA Erosion Hazards study with a goal of determining the relationship between material properties and erosion rates and processes. Through a combination of regional and detailed, site-specific investigation, we hope to provide improved tools for scientists, planners, and engineers for coastal management and development decisions.
REFERENCES