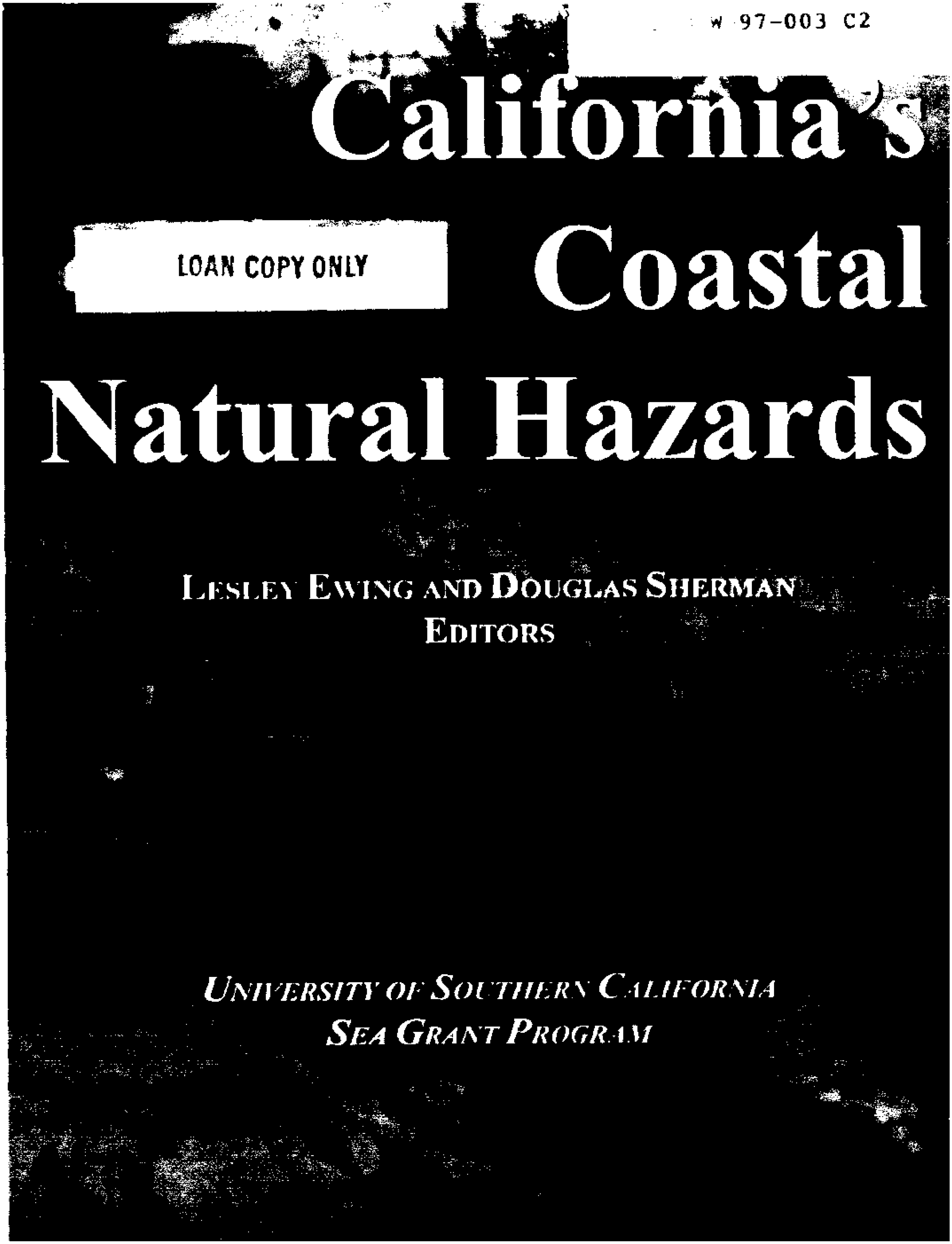

California's Coastal Natural Hazards

LESLEY EWING AND DOUGLAS SHERMAN
EDITORS

UNIVERSITY OF SOUTHERN CALIFORNIA
SEA GRANT PROGRAM

CALIFORNIA'S COASTAL NATURAL HAZARDS

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PROCEEDINGS FROM THE CONFERENCE HOSTED BY THE
CALIFORNIA SHORE AND BEACH PRESERVATION ASSOCIATION
AND THE
UNIVERSITY OF SOUTHERN CALIFORNIA
SEA GRANT PROGRAM

NOVEMBER 12-14, 1997
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INTRODUCTION

The "Urban Ocean" is the theme of the University of Southern California Sea Grant Program. Under this rubric, the program's resources are focused on the opportunities and challenges arising from the juxtaposition of concentrated human development and coastal and marine ecosystems. The theme is readily applicable to the field of natural hazard studies, where the greatest risks are usually associated with the concentrations of human settlement or development. The California Shore and Beach Preservation Association (CSBPA) is concerned with the proper management of the state's beaches as a resource. The missions of the two organizations have converged on the theme of this conference, "California's Coastal Natural Hazards."

In the summer of 1996, Dr. Douglas Sherman, Director of USC Sea Grant, came to a CSBPA Board meeting and proposed that the Sea Grant Program and CSBPA begin working together on a conference to update the conference on "California's Battered Coast: A Conference on Coastal Erosion" which was convened in 1985. As a result of this collaboration CSBPA and USC Sea Grant held a joint conference in Santa Barbara, California, November 12 - 14, 1997 and these proceedings are a lasting record of that event.

What has changed since the 1985 first "Battered Coast" Conference? One of the most noticeable changes relates to El Niño. It was during and after the 1982/83 El Niño winter that El Niño became a household term. Very few people recognized in 1982 that conditions were developing in the eastern Pacific that could lead to the sequence of storms that battered California in late 1982 and early 1983. The enormity of these storms spawned extensive study of El Niño, Southern Oscillation and global ocean/atmosphere climate modeling. The 1985 conference was a follow-up to the dramatic coastal changes and coastal damage that occurred during the 1982/83 El Niño. By 1997 when this conference was held, we were anticipating an El Niño winter that could be of a similar magnitude as the 1982/83 event. Dr. Reinhard Flick spoke at the opening session of the conference about the various climatic indicators for El Niño, comparing the ocean temperatures and atmospheric conditions in the fall of 1997 with the fall and winter of 1982. He noted that the question at that time was only how significant it would be; there was no question about whether it would occur. With the new awareness of El Niño and detailed monitoring of ocean and atmospheric conditions, we can better anticipate El Niño events and are now far better equipped to undertake pro-active, rather than re-active storm protection.

A second change since the original Battered Coast Conference is the growing number of people who live, work and recreate along California's coast. As noted in the presentation by Dr. Gary Griggs, the population of California is expected to reach 50 million by the year 2020. At the conference, Dr. Karl Nordstrom and Dr. Griggs both discussed some of the ways humans have altered the coast and the constraints and challenges that this poses for coastal management. Dr. Nordstrom focused on the physical alteration of coastal landforms and the issues involved with accommodating human uses of the coast while "retaining an image of the coast that reflects the natural processes which provide its special appeal." Dr. Griggs focused on the hazardous conditions which are inherent to most of the California coast, the extent of storm damage which has arisen from earlier El Niño and non-El Niño winters and concludes in, "California's Coastline: El Niño, Erosion and Protection," that "significant changes are needed in how we approach and deal with coastal hazards and the continuing pressure to develop in oceanfront areas."

A third change since the Battered Coast Conference is the heightened interest in beach nourishment. At the Battered Coast Conference, there were a number of discussions of sand budgets and changes in littoral sand supplies. Katherine Stone and Benjamin Kaufman presented a paper at the conference about a new concept of Sand Rights -- a legal system for maintaining the supplies of sand which are necessary for beach preservation. While David Potter discussed the feasibility of sluicing sand from dams, James Walker and Amy Tatami discussed the use of perched beaches and submerged breakwaters to protect beach areas.

By the 1997 conference, beach nourishment was a common focus of more than half the presentations. In the morning session, Dr. Richard Seymour discussed the findings of the National Research Council's Committee on Beach Nourishment and Protection, and concluded that properly engineered beach nourishment had been found to be a valuable and viable technique for beach protection. Orville Magoon and Dr. Billy Edge presented a paper which reintroduces the issue of Sand Rights and proposed statements for both sand rights and sand responsibilities. Kim Sterrett provided the results of a needs survey for coastal communities, which found that of the 120 miles of shoreline which was in need of some type of protection, beach nourishment was the preferred approach for over 40 miles of coast. On the same topic, Chris Webb, Keith Till and Steve Badum discussed a recently completed beach nourishment at Seal Beach; then Howard Cumberland, Mitch Perdue and Lawrence Honma presented a paper about a beach nourishment study for the Navy Homeporting project in San Diego. Moi Arzamendi and Mike Hemphill presented an analysis of the geotechnical concerns of using dredge material for beach nourishment and lagoon enhancement; and Kenneth Lilly and Don Kingerey discussed the design of shoreline protection at Ocean Beach and a method for beach construction seaward of a geotextile revetment. Finally, Paul Jenkin's presentation discussed the opportunity to use beach nourishment to protect the bike path at Surfer's Point, downcoast of the Ventura River.

Many issues and paper topics that were included in the Battered Coast Conference are repeated in the 1997 conference. The three main topics from the Battered Coast Conference were: 1) examination of shoreline types; 2) discussion of the structural versus non-structural approaches to shoreline management; and 3) the government's roles in shoreline management. The 1997 conference included a session on the science and engineering for coastal hazard reduction that examined shoreline types and presented new approaches for studying shoreline types. Deidre Scholar and Gary Griggs presented a paper on the general dynamics and concerns for pocket beaches, and Peter Gadd discussed field work on sediment dynamics for a pocket beach in Crescent Bay, Laguna Beach. Mark Capelli and Jim Baillard both discussed the Santa Barbara and Ventura coast, with Mark Capelli discussing the Isla Vista area and Jim Baillard discussing coastal dynamics and the results of his field research in the two county area. Chris Flynn discussed the dynamics of river mouths and David Skelly and Michelle Kremer presented a proposed surf enhancement reef that may be constructed in El Segundo. Benjamin Benumof, Laura Moore and Gary Griggs assessed the uses of soft copy photogrametry in determining coastal erosion, and Anders Rindell and James Hollarn analyzed the use of CCD Digital Video for studying beach width.

The issues of structural versus non-structural solutions and the government's role in coastal management were tied together in the discussion by Jon Moore, in which he concluded that we will continue to have piecemeal structural responses to erosion as long as government leaves the responsibility for erosion response to the individual property owner. Jon Moore posed two challenges: to the engineering profession, for creating approaches to shoreline hazards, and to government for more responsibility in the overall management of the shoreline. David Fischer and M. Concepción Arrendondo then presented a survey of communities in Southern California in which they found that the governance of coastal hazards tends to be reactive: "not nearly enough is being done [by municipalities] to protect the Southern California coastline...(and) municipalities are taking inconsistent approaches to local coastal planning and protection." Some of these ideas were echoed by Ventura County Supervisor John Flynn as he introduced his visions for regional coastal management and the innovative ways for local governments to fund shoreline enhancement projects; and by Pedro Nava in his discussion on the role of regulatory policy in shoreline management. Finally, these ideas were discussed by Steve Sachs in his discussion of what the San Diego area had and had not been able to accomplish through the shoreline committee of the San Diego Association of Governments. Gary Magnuson discussed some of the opportunities for getting involved in federal shoreline management policy, Howard Marlowe discussed the role which the American Coastal Coalition has developed for shaping federal shoreline policy, and Robert Eichblatt and Bob Fisher presented the idea of CalCoast, coalition of California coastal communities which could voice coastal concerns to the state legislature.

The 1997 conference concluded with a half-day long Workshop on Beach Nourishment. Douglas Sherman presented results of his research on the effects of introducing a large volume of fines into the nearshore environment, Steve Jantz and Chris Webb discussed a program which the city of Carlsbad is developing to use inland sources of sand for beach nourishment, and Steve Aceti discussed San Diego County's plans to expand the Carlsbad program county-wide. These presentations were followed by a general discussion of beach nourishment.

The 1985 Battered Coast Conference followed one of the most devastating periods of coastal storm damage in California history. Over $100 million in damages occurred in January 1983 -- 3000 homes and 900 businesses were damaged; 27 homes and 12 businesses were destroyed and 11 coastal counties were declared disaster areas. The 1985 conference brought together coastal geologists, coastal engineers and people in government hoping to, as Mel Nutter, Chairman of California Coastal Commission said, "set the framework for cooperative efforts to plan our shoreline," especially in determining "the physical and the political framework of California's shoreline erosion response." Since 1985, there have been several positive changes in the physical framework. We have learned a lot more about the California coast and the storm conditions, which cause much of the major coastal damage. We have developed or applied new tools to study coastal processes and coastal change and have recognized better the differences between shoreline protection and beach protection. The positive changes to the political framework are less easy to identify. The growing role of regional governments in shoreline management and the increasing interest in regional responses to shoreline erosion through beach nourishment are positive changes, as is the creation of state and federal coastal coalitions.

Perhaps the most lasting benefit to the physical and political framework of shoreline erosion response is in that at the 1997 conference, it was sometimes difficult to distinguish among arguments made by coastal geologists, engineers, and people in government. The discussions which started with the original Battered Coast Conference have continued in many different forums; the groups who were viewed in 1985, as being different or even adversarial, in 1997, have developed open lines of communication and often, have joined forces to find the best approaches for managing our Battered Coast.

The organization of the conference, "California's Coastal Natural Hazards," and the subsequent production of this volume have required substantial time and effort from many individuals representing several organizations. Credit is due first to the Board and members of California Shore and Beach Preservation Association and its past president, Reinhard Flick (California Department of Boating and Waterways), whose enthusiastic support and participation enabled the conference to succeed. Thanks also to Gabriella Jimenez and Leslie Shea for the "on-the-ground" logistic efforts that made the conference flow smoothly. Thanks to Phyllis Grifman for overall conference and production supervision. Finally, a special acknowledgement is due of the efforts of Rick Hayduk and Jean Todisco from USC Sea Grant; Rick's excellent design and publishing skills have allowed us to create a useful volume out of the conference papers, and Jean's assistance on the paper references and attention to detail in the text has been invaluable.

Lesley C. Ewing
Douglas J. Sherman

October, 1998

CONFERENCE SCHEDULE

DAY ONE NOVEMBER 12, 1997

8:30 **Plenary Session — Introduction**

9:30 - 10:00 **BREAK**

10:00 - 12:00 **Revisiting the Battered Coast** (Chaired by Jim McGrath)

Introduction to The Battered Coast — Gerry Kuhn

Evolution of Landforms on Human-Altered Coasts — Karl Nordstrom

El Niño 97 Reinhard Flick

Beach Nourishment and Protection Richard Seymour

Beach Nourishment In San Diego — Howard Cumberland

Perspectives on the California Coast Since 1985 — TBA

12: 15 - 1:45 **LUNCH — Denise Ducheny, Member, California State Assembly**

2:00 - 3:30 **Science and Engineering for Coastal Hazard Reduction** (Chaired by Laura Moore)

CCD Digital Video and Conventional Imagery Studies of the Beach Width and Shoreline Monitoring Anders Rindell and James Hollarn

Pocket Beaches of California — Deirdre Scholar and Gary Griggs

Coastal Processes within a Small Pocket Beach, Crescent Bay, Laguna Beach California — Peter Gadd

A Protocol for River Mouth Breaching — Chris Flynn

FEMA and State-of-the-Art- Coastal Erosion Mapping Along the San Diego County Shoreline Benjamin Benumof and Laura Moore

3:30 - 4:00 **BREAK**

4:00 - 5:30 **Case Studies** (Chaired by George Domurat)

Overview of Survey Demand for Coastal Protective Projects, Soft and Hard Alternatives — Kim Sterett

Reducing Storm Damages and Increased Economic Benefits in Seal Beach through Beach Nourishment — Chris Webb, Keith Till and Steve Badum

Geotechnical Engineering Considerations for the Bataquitos Lagoon Enhancement Project — Moi Arzamendi and Mike Hemphill

Ocean Beach, San Francisco: Protection and Management of an Eroding Shoreline — Kenneth Lilly and Don Kingery

Surfrider Foundation Surf Enhancement Project · David Skelly and Michelle Kremer

Local Government Planning for Coastal Hazards — David Fischer

7:00 - 10:00 **EVENING — NO HOST BAR**

DAY TWO NOVEMBER 13, 1997

8:00 - 9:30 **The Local Coast** (Chaired by Steve Scholl)

Introduction to Santa Barbara/Ventura Coastal Conditions — Jim Baillard

Fear and Loathing in Isla Vista — Mark Capelli

Growing the Beaches (a slide show) — A. Paul Jenkin

Local Coastal Issues — Jon Moore

Ventura Flood Control- Debris Basin Cleanout for Beach Nourishment — Karl Treiberg

9:30 - 10:00 **BREAK (and Hotel Checkout for Wednesday Departures)**

10:00 - 11:15 **Linking Coastal Science to Public Policy and Decision making** (Chaired by Tom Kendall)

Maintaining the Federal Role in the Protection of California's Shoreline — Howard Marlowe

Task Force Update — Robert Eichblatt and Bob Fisher

Sand Rights — Orville Magoon

Two Successful Coastal Projects and a Third on the Way — Ann Kulchin

11:30 - 12:30 **Panel Discussion on Redefining the Mission and Direction of Regional Coastal Management** (Chaired by Karin Strasser-Kaufman)

John Flynn, Ventura County Board of Supervisors

Others TBA

1:00 - 5:00 **BOX LUNCH AND FIELD TRIP *****

Santa Barbara to Port Hueneme — Jerry Nowak

***Santa Barbara to Port Hueneme is a long stretch of coast to cover in a short amount of time. To get favorable tide conditions and to let people make outbound airline reservations, we must depart the hotel promptly at 1:00 PM. A box lunch will be served on the bus.

FRIDAY NOVEMBER 14, 1997

8:30 to 12:00 **WORKSHOP ON BEACH NOURISHMENT**

Many coastal communities in California are now viewing beach nourishment as an opportunity to enhance their recreational areas and avoid or minimize the need for seawalls or revetments. Due to the increased interest in Beach nourishment, the nature of beach nourishment in California is changing to expand the availability of acceptable material and acceptable receiver locations. Existing policies and regulations for beach nourishment do not fully address these changing situations.

Resources and regulatory agencies, local and regional governments, environmental organizations, property owners and interested individuals are invited to this workshop to participate in discussions about the regulatory framework necessary to address the evolving concerns of beach nourishment.

For more information on the workshop, please contact Walt Crampton at (619) 573-1777.

THE EVOLUTION AND VALUE OF LANDFORMS ON HUMAN-ALTERED COASTS

Karl F. Nordstrom
Professor, Institute of Marine and Coastal Sciences

INTRODUCTION

Many studies call attention to the way human altered coasts differ from their natural counterparts in terms of loss of natural features, changes in sediment budgets, and changes in the degree of coastal hazard (Hall and Pilkey 1991; Finkl 1994; Morton *et al.*, 19,94; Nordstrom 1994), but there is little attention devoted to differences in coastal evolution at the scale of individual landforms. This paper presents a summary of results of a program designed to identify the variety of landforms created or altered by humans and to evaluate losses and gains in their resource potential. The purposes of the paper are to identify: 1) the ways landforms are altered initially to suit human needs; 2) the ways they are altered subsequently through interaction with buildings and shore protection structures; 3) the characteristics of human-altered landforms; 4) the relationship between the perceived resource value of landforms and the ways they are modified to maximize this value; and 5) the constraints to planning and policy controls that contribute to continued loss of natural landform characteristics.

ALTERATION OF LANDFORMS TO SUIT HUMAN NEEDS

Ways that landforms are altered to suit human needs (Table 1) vary from total elimination to subtle changes that affect their appearance or surface mobility but not their overall form or function.

Table 1. Ways that landforms are altered to suit human needs.

- Elimination for alternative uses
    - Buildings.
    - Transportation routes and terminals.
    - Alternative recreation surfaces.
    - Non-coastal (landfills, farm fields).
    - Mining.
        - Construction aggregate.
        - Minerals.
        - Liming material and substrate for crops.
        - For covering landfills.

- Alteration through use
    - Pedestrian trampling and vehicle use.
        - For access.
        - For direct recreation

- Waste disposal
    - From day use tourist activities.
    - Random disposal of cars, machinery.
    - From beach cleaning.
    - From commercial activities.
- Agriculture and harvesting.
    - Planting forests.
    - Gathering flowers, fruits, seaweed.
    - Removing vegetation for fuel, thatch.
    - Grazing.
- Extraction and recharge
    - Drinking water.
    - Oil and gas.
    - Watering gardens and waste-water disposal.
    - Concentrating surface runoff.
- Military
    - Active uses (bombing, maneuvers).
    - Fortresses and bunkers.
    - Harbor structures.

Reshaping
- Increasing levels of protection
    - Scraping beaches.
    - Bulldozing dunes.
    - Breaching barriers to control flooding.
    - Dredging inlet channels to cause deposition.
- Preventing or alleviating sand inundation
- Enhancing recreational or commercial use
    - Widening beaches for recreation platforms.
    - Eliminating obstacles to access.
    - Providing or retaining views of the sea.
    - Creating platforms for cabanas, pavillions.
    - Clearing the beach of litter.
    - Maintaining navigation channels.
- Enhancing environmental values
    - Creating more naturalistic landscapes.
    - Altering environments for wildlife.

Altering landform mobility
- Placing barriers to trap sand.
- Armoring surfaces
- Introducing new sediments into beach, dune.
- Creating or closing inlets.
- Relocating channels or altering cycles.
- Altering natural vegetation
    - Controlling density (mowing, grazing, fires).
    - Planting species to increase diversity.
    - Introducing exotics.
    - Changing growth conditions by nourishment.

- Altering external conditions
  - Mining and damming streams.
  - Reducing basin source area.
  - Changing nutrient levels or acidity (pollution).

Beaches and dunes are eliminated to facilitate construction of buildings (Figure 1) (Kuhn and Shepard 1980; Healy *et al.*, 1990), public support infrastructure, such as roads and railroads (Cencini and Varani 1989; Peña *et al.*, 1992), airports and landing strips (Mather and Ritchie 1977) and parking areas. They may be eliminated for recreational uses that do not require buildings, such as golf courses (Mather and Ritchie 1977; Doody 1989) or for uses that have little specific value in a coastal environment, such as landfills or fields for specialized farming (Cencini and Varani 1989). Landforms also may be eliminated through mining operations (Mather and Ritchie 1977; Hesp and Hilton 1996), mostly for construction aggregate or for beach and dune nourishment.

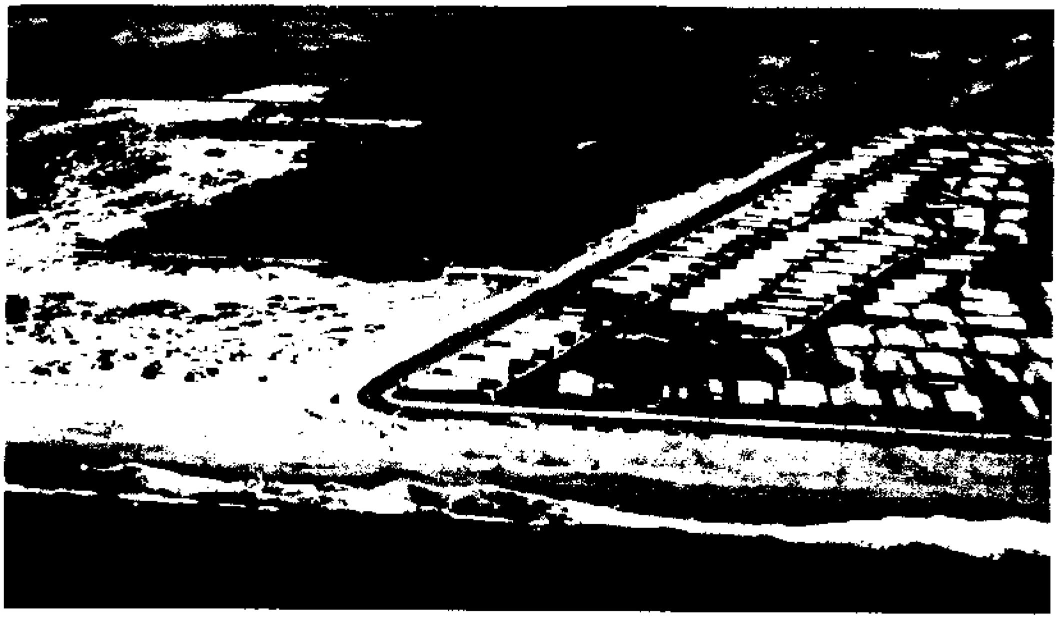

Figure 1. Oxnard Shores, California, 1984, showing loss of dune and trucation of the beach due to construction of buildings and roads.

Landforms that are not completely eliminated can be altered through use (Table 1). The most widely reported alteration is trampling by pedestrians and off-road vehicles (Eastwood and Carter 1981; Godfrey and Godfrey 1981; Anders and Leatherman 1987; Bonner 1988; Andersen 1995). Trampling may occur because a landform is: 1) an access way to another location (e.g. trampling of dunes by visitors to the beach); 2) the destination for passive recreational activity (seeking seclusion in dunes); or 3) the direct target of consumptive use (sand sliding, dune busting).

Waste disposal can include items that are relatively inconspicuous and temporary (products from day use tourist activities) or items that are large, durable and not associated with beach use (cars and farm equipment) (Mather and Ritchie 1977). Waste products may comprise their own distinctive landforms, such as the disposal mounds associated with beach cleaning (Nordstrom and Arens in review) or mine waste (Bourman 1990; Paskoff and Petiot 1990; Humphries and Scott 1991; Smith *et al.*, 1994).

Some agriculture and harvesting activities, such as picking natural decorative plants (Olsauskas 1995), can have little effect on viability of coastal landforms; other activities, such as planting forests (Blackstock 1985; Sturgess 1992; Favennec 1996), can change the surface cover and mobility of landforms. Activities, such as harvesting kelp or removing vegetation for fuel and thatch (Randall 1983; Westhoff 1985; Skarregaard 1989; Hewett 1985) may have little impact when practiced on a small scale, but they may have pronounced cumulative effects. Grazing is an activity that may be seen as beneficial or harmful depending on the level at which it is practiced (Mather and Ritchie 1977; Hewett 1985; Westhoff 1985).

Extraction and recharge of drinking water and artificial drainage can alter vegetation in dune systems (Westhoff 1985; van Dijk 1989). Extraction of oil and gas (Inman *et al.*, 1991; Flick 1993; Wiegel 1994; Bondesan *et al.*, 1995) can increase flooding and wave action. Watering lawns and gardens, waste-water disposal and concentrating surface runoff can affect stability of slopes on high relief coasts (Kuhn and Shepard 1980; Dias and Neal 1992; Griggs 1994).

Active military uses (bombing, maneuvers) can have positive effects on landforms by excluding more destructive recreational uses (Doody 1989) or negative effects by destroying vegetation cover or landform shape through direct use or through efforts to remove unexploded ordnance (Demos 1991). Fortresses and bunkers that no longer have military value often survive for long periods to have a passive effect on coastal processes and landforms (Mather and Ritchie 1977; Guilcher and Hallégouët 1991; Jensen 1995). Many effects of military structures are highly localized and confined to military reservations, but the effects of harbor structures can change sediment budgets for many kilometers along the coast.

Landforms may be reshaped to accommodate a wide variety of uses (Table 1). Reshaping to increase levels of protection includes scraping beaches to change local sediment budgets (Tye 1983; McNinch and Wells 1992; Kana 1991), bulldozing dunes to create more effective barriers to flooding (Nordstrom and Arens in review), breaching barriers fronting lagoons to control flooding (Orford *et al.*, 1988) and altering navigation channels to change erosion/deposition cycles through artful dredging (Farrell and Sinton 1983; Kana 1983).

Inundation by sand that is washed (Bush 1991) or blown (Sherman and Nordstrom 1994) onto boardwalks, roads patios and yards may be alleviated by removing incipient sand deposits or excavating buried facilities. These actions can be highly localized and conducted manually, or they can occur at the regional scale and involve use of heavy equipment following major storms (Nordstrom and Arens in review).

Reshaping to enhance recreational or commercial use includes creating wider beaches as recreation platforms, eliminating dunes and other topographic obstacles to provide easy access or views of the sea (Nordstrom and Arens in review; Cortright 1987), raising the elevation of the backbeach to provide a platform for cabanas and pavilions (Cencini and Varani 1989; Paskoff 1992) and clearing the beach of litter (Hotten 1988; Bodge and Olsen 1992; Atherley *et al.*, 1993). Alteration of beaches and dunes to enhance environmental value is less common but has been accomplished to create naturalistic contours (van Bohemen and Meesters 1992), to create environments that encourage bird nesting or breeding (Randall and Doody 1995) or to flush pollutants or enhance target aqueous species (Tiffney and Andrews 1989).

Intentional alteration of landform mobility (Table 1) can be accomplished by restricting movement using barriers or by changing surfaces or internal characteristics to alter the effectiveness of the processes acting on them. Planting vegetation and placing sand fences to trap sand (Godfrey and Godfrey 1973) are among the most common means of restricting mobility, but a variety of other stabilizing materials are used, including straw (van der Putten and Kloosterman 1991), tires (Western Australia Department of Planning and Urban Development 1993), biodegradable matting (Demos 1991) and bitumen spray (Ritchie and Gimingham 1989). Introducing new sediments into the beach or dune matrix can change resistance to wave erosion and can be done intentionally to reduce erosion rates (Nelson 1991) or incidentally, when opportunistic sources are used in nourishment operations, rather than more costly sources that are compatible with native materials. Human actions change inlet characteristics by creating new inlets (Wiegel 1992; Bodge 1994), closing inlets (Sorensen and Schmeltz 1982; Louters *et al.*, 1991; Terchunian and Merkert 1995), preventing new inlets from forming (Ehlers and Kunz 1993), relocating inlets or channels (Kana 1989; Møller 1990) or altering the timing of natural cycles (Webb *et al.*, 1991). Natural vegetation may be altered by mowing (Hewett 1985; Westhoff 1985), setting fires (Chapman 1989), planting diverse species (Mauriello 1989), introducing exotics (Cooper 1958; Chapman 1989; Doody 1989; Sturgess 1992; Espejel 1993) and changing temperature and drainage through nourishment operations (Bodge and Olsen 1992).

Alterations of conditions external to the boundaries of landforms (Table 1) may affect their evolution by changing sediment budgets and viability of vegetation. Sand supply to the coast from fluvial sources may be reduced due to mining and damming streams and reducing basin area in land reclamation projects, resulting in a change from accreting shorelines to eroding shorelines (Postma 1989; Innocenti and Pranzini 1993; McDowell *et al.*, 1993; Niemeyer 1994). Changes to the viability of vegetation occur due to alterations in nutrient levels or acidity due to pollution in precipitation (Westhoff 1989; van Boxel 1997).

The categories of activities indicated in Table 1 are limited to those that have large-scale implications or are frequently reported. Many local human actions could be added, including inscribing graffiti and carving caves (Komar 1979; Lee 1980; Lee and Crampton 1980; Dias and Neal 1992) and using dunes for toilets or for cemeteries (Western Australia Department of Planning and Urban Development 1994; Mather and Ritchie 1977).

EFFECTS OF STRUCTURES ON PROCESSES, LANDFORMS AND SEDIMENT AVAILABILITY

Structures can have direct impacts on landforms in addition to the alterations associated with initial construction and use of structures identified in the previous section. Shore protection structures change wave refraction patterns and wave breaking, surf-zone circulation, swash velocity, duration and elevation, beach groundwater elevation and beach slope variability; these structures also can re-direct sediment transport, interrupt existing beach-bar systems, create rhythmic features on the beach and offshore and create differences in sediment characteristics updrift and downdrift (Orme 1980; Sherman *et al.*, 1990; Bauer *et al.*, 1991; Gayes 1991; Plant and Griggs 1992; Short 1992; McDowell *et al.*, 1993). Structures on the upper beach provide barriers that enhance deposition of aeolian transport and dune accretion (Nersesian *et al.*, 1992; Nordstrom *et al.*, 1986). Jetties cause migration of preexisting channels, displace ebb tidal deltas and associated bars, induce lower nearshore gradients, reduce breaker heights, change sediment budgets, change the likelihood of dune building and growth of vegetation, convert bidirectional (erosion-accretion) cycles to unidirectional cycles and eliminate inlet throat beaches and bare sand areas that provide habitat (Nordstrom 1987; Roman and Nordstrom 1988; Short 1992; Bodge 1994).

Piers and pilings create scour holes and cause differences in depth, slope, and vertical variation of beach profiles related to pile size and spacing (Miller *et al.*, 1983; Nicholls *et al.*, 1995). They also affect local longshore transport (Miller *et al.*, 1983; Weggel and Sorensen 1991) and can create a tombolo-shaped bulge in the shoreline (Weggel and Sorensen 1991). Shore-parallel promenades and boardwalks can provide local traps for wind blown sand. Minor beach structures, such as cabanas and pipes, locally alter accretion and erosion on the beach (Otvos 1993; Bandeira *et al.*, 1990) and create distinctive but temporary landforms.

Sand fences alter natural flow patterns and trap sand, thereby stabilizing bare sand surfaces, accelerating natural accretion rates and concentrating accretion over smaller zones than occurs with natural vegetation. These structures control dune morphology by adjusting porosity, height, orientation, type of opening, number and distance separating fence rows (CERC 1984; Hotta *et al.*, 1987, 1991; Snyder and Pinet 1981).

Buildings alter wind speeds, alter depositional patterns and separate aeolian sources from sinks. Their size and spacing affect flow directions and speeds, and they can create scour zones between them and deposition zones landward or in front of them (Nordstrom *et al.*, 1986). High rise structures can cause local reversals in regional wind direction and create pronounced upward flows and scour depressions (Gundlach and Siah 1987; Nordstrom and Jackson 1997). Buildings that end up in the swash and breaker zones obstruct or redirect waves and currents and can cause changes in the slope of the beach and the shapes of nearshore bars (Gayes 1991). Buildings can remain on the beach and affect processes and beach response years after they are abandoned (Meyer-Arendt 1993). Swimming pools and septic systems provide obstructions to flow and increase turbulence and scour (Nnaji *et al.*, 1996; Yazdani *et al.*, 1997). Roads and parking lots provide impermeable and unobstructed pathways for overwash and entrained sand (Hall and Halsey 1991; Fletcher *et al.*, 1995) and can act as transport surfaces separating sources from sinks.

Marinas and harbors replace natural coastal environments, break up shoreline orientation, change wave patterns, trap sediment, deflect sediment offshore and starve adjacent beaches. They also have indirect effects, such as changes in bottom configuration caused by dredging and accelerated erosion and accretion of adjacent beaches caused by construction of jetties or breakwaters built to enhance navigation (Wiegel 1994; Anthony 1994).

Specialized landforms can be created that have little large scale impact but may be of great local interest, including artificial islands and tombolos (Leidersdorf *et al.*, 1990; Nagao and Fujii 1991), artificial shoals to enhance surfing (Wiegel 1993) and sand seawalls to protect mining operations (Smith *et al.*, 1994). These artificially-created coastal landscapes can evolve naturally, once built.

ALTERATIONS OF CHARACTERISTICS OF COASTAL LANDFORMS BY HUMAN ACTION

The locations of human altered landforms are dictated by human preference, not the interplay of natural processes (Nordstrom 1994), resulting in spatial relationships different from those that would occur under natural conditions (Table 2).

Table 2. Characteristics of human-altered coastal landforms.

Location
  Created in places where they may not occur naturally.
  Eliminated in places where they would occur normally (sand drift, overwash).
  Displaced (e.g. location of breakers, surf, accretion and erosion zones.

Sedimentology
  Introduced sediments may differ in size, sorting, shape, mineralogy, texture, color.
  Aeolian transport on introduced sediments may create a lag surface layer.
  Drainage may be changed by impermeable layers and compaction by vehicles.
  Bulldozed dunes have poorly defined internal stratification.
  Dunes emplaced by pumping in a slurry reflect sorting by hydraulic, not aeolian processes.
  Substrate deposited artificially lacks roots and filaments.

Orientation
  Structures transform natural beaches into smaller drift cells.
  Beaches affected by structures achieve a new planform
  Nourishment can fill reentrants, creating a continuous beach.
  Erosion hot spots on nourished beaches create local crenulations.
  Dunes often more linear to function as continuous barrier to flooding.
Height
  Nourished beaches are built higher to achieve protection goals.
  Backbeaches may be built higher to accommodate use structures (cabanas, restaurants).
  Dramatic elevation differences occur on opposite sides of protection structures.
  Low beaches occur where shore-parallel walls restrict development of upper beach profile.
  Dunes are often lower to maintain views of the water from shorefront homes.
  Dunes are higher where safety is the principal value.
  Lower dune heights may result where sediment in peaks is used to fill low portions.
  Low points may be created in dunes at intervals alongshore to favor beach access.

Topographic variability
  Low cross-shore variability where:
    Simple profile shape is adopted to facilitate construction and calculation of fill volumes.
    Recreation beaches are graded flat to facilitate beach access and use.
    Beach cleaning eliminates incipient dunes.
    Truncation by landward structures limits formation of storm berms and dunes.
  Variability alongshore may be increased by shore-perpendicular structures.
  Dune creation by sand fences and bulldozing causes steeper gradients.
  Dunes are of consistent height to minimize blowouts or retain predictable level of safety.

Width
- Construction on or near the beach creates narrower beaches.
- Nourished beaches may be temporarily wider.
- A single narrow ridge is preferred for dunes in developed communities.

Surface characteristics
- Removal of wrack eliminates biomass and nutrients and disturbs eggs.
- Beach cleaning produces a featureless beach with an artificial look and little natural value.
- Native species on stabilized protective dunes are usually less diverse.
- Landforms on landward side of dune may be planted with exotics.

Mobility
- Most protection structures are designed to reduce mobility.
  - Reduction of long term erosion rates.
  - Truncation of short term cycles of erosion and deposition.
- Dunes shaped according to human needs are usually protected in place.
- Coarse surface lag resists deflation.
- Human attempts to maintain a sand-free surfaces prevent landward accumulations.
- Aeolian transport may be increased during construction, when vegetation is removed.
- Mobility due to beach nourishment can greatly exceed natural rates.

Timing of cycles of landform change
- Protection projects introduce cycles related to administrative or logistical constriants.
- Cycles of dune destruction and rebuilding are shortened to annual or storm periodicities.
  - Dunes eliminated to provide beach space in summer and re-built for winter protection.
  - Regularly scheduled repair of dunes usually creates an annual cycle.
  - Sacrificial protective dunes are rebuilt soon after small storms.
  - Clearing of deposits from small wind events may occur at periodicities of small storms.

The sediments introduced in beach nourishment and dune building operations and the methods used can change both the surface and subsurface characteristics dramatically (Hotten 1988; Rouch and Bellessort 1990; Adriaanse and Choosen 1991; Wiegel 1992; van der Wal 1997). Landform orientation changes as structures transform natural beaches into smaller drift cells (Byrnes *et al.*, 1993). Nourishment operations can create a more continuous beach planform between groins or result in a less continuous planform, such as through creation of erosional hot spots associated with beach fill operations (Hamilton *et al.*, 1996). Dunes often become more linear, due to a conservative, protective approach to management based on the value of dunes for protection. Human-altered beaches and dunes can be either higher or lower than pre-existing natural beaches, depending on the rationale for the landform conversion (Table 2).

Human-altered beaches usually have less topographic variability measured across the shore, but topographic variability alongshore may be increased by shore-perpendicular structures as a result of trapping sand or redirecting it offshore. Deposition caused by sand fences and bulldozing usually occurs in narrower zones than under natural conditions, resulting in steeper gradients, although some bulldozed foredunes may be constructed with a gentle slope to facilitate planting and reduce the likelihood that erosion scarps will form (Nordstrom and Arens in review). Tops of dunes shaped by bulldozers may be of consistent height and shape to provide a predictable measure of safety against wave overwash and flooding or minimize blowout formation. Small hummocks, resulting from mechanical deposition, may occur on the surface of bulldozed dunes that are not subsequently re-shaped to provide a smooth surface. Surfaces of artificial dunes can be shaped to simulate natural dunes (Adriaanse and Choosen 1991; van Bohemen and Meesters 1992), but most artificial dunes are built to be more linear than their natural counterparts for ease of management (Nordstrom 1990).

Variations in beach width may be more a function of landscaping efforts and use of protection structures than natural factors (Kana 1993). The width of human altered landforms is usually narrower than natural landforms. Construction on or near the beach and prevention of subsequent onshore migration of the beach profile usually results in narrow beaches, although nourishment may temporarily create a wider beach than under natural conditions. A single narrow ridge may be considered the optimum shape for dunes in developed communities (Mauriello 1989) to maximize beach width, allow easy access and retain views of the sea from shorefront residences.

The surface characteristics of recreation beaches (Table 2) can be altered by removing wrack and flotsam, thereby eliminating biomass and nutrients and disturbing eggs (Hotten 1988). The clean, processed look of raked beaches (Figure 2) appears artificial and has little natural value. Native species are often less diverse on protective foredunes because a single species is preferred for stabilization. Landforms that are allowed to survive on the landward side of the dune often are planted with exotic species (Nordstrom and Arens in review).

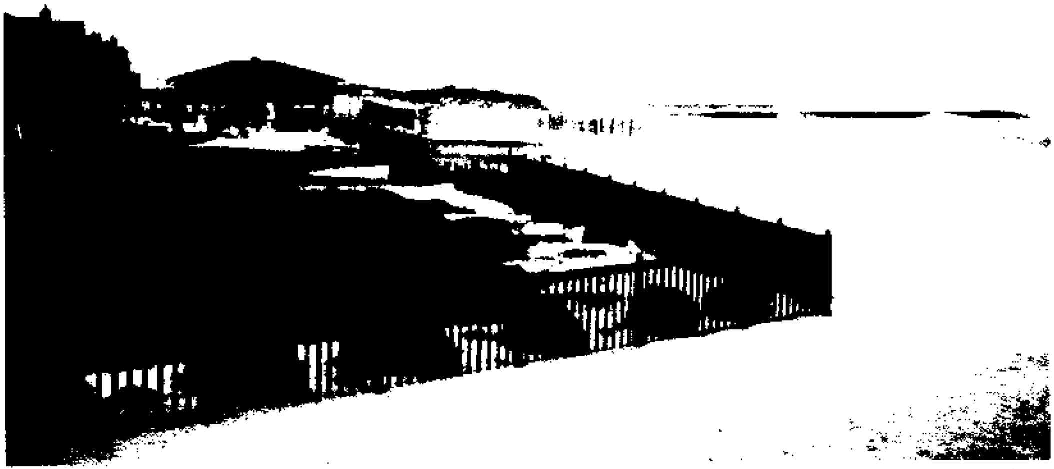

Figure 2 Atlantic Beach, New York, showing flat, bare sand beach considered optimal for recreational use in urban environments and suburban conception of landscaping on backbeach.

Most direct human actions are designed to reduce landform mobility to protect buildings and infrastructure or provide more predictable navigation channels and recreation surfaces, although mobility can be increased during construction phases, when stabilizing vegetation is removed (González-Yajimovich and Escofet 1991) or when landforms are adjusting to achieve a new equilibrium configuration just after structures are in place. Mobility due to beach nourishment can greatly exceed natural rates (Pilkey and Clayton 1987), although this mobility is an unwanted byproduct of these operations.

Human actions dramatically change the cycles of landform change. The timing of nourishment projects is prescribed by the administrative time of government projects rather than conditions at the site (Kana 1993). These cycles may be longer than natural cycles of beach change, but they are aperiodic and may have no direct relationship to natural cycles. Dunes in developed areas may be eliminated in summer to provide a recreation platform and re-built in the autumn to provide storm protection, resulting in a seasonal cycle. Regularly scheduled repair of dunes is usually conducted on an annual basis. Dunes in developed areas are often closer to the water than in natural areas and are eliminated by smaller storms than would eliminate them in natural areas; they are usually rebuilt immediately after the storm rather than waiting for natural processes to restore them. As a result, sacrificial dunes may have several cycles per year. Clearing of deposits from small wind events by residents may occur at periodicities of small storms. All of these dune cycles are of shorter term than natural cycles that are related to destruction during major storms and subsequent rebuilding by natural processes (Nordstrom and Arens in review).

VALUES VS DEGREE OF NATURALNESS

The potential for modifying natural beaches and dunes to artifacts and for reversing this process in order to restore coastal landscapes to more naturally-functioning systems depends on human values for coastal resources and the perceived role of natural components in providing these values. The most commonly occurring human values and their associated alterations or uses may be placed in a continuum (Figure 3) to highlight

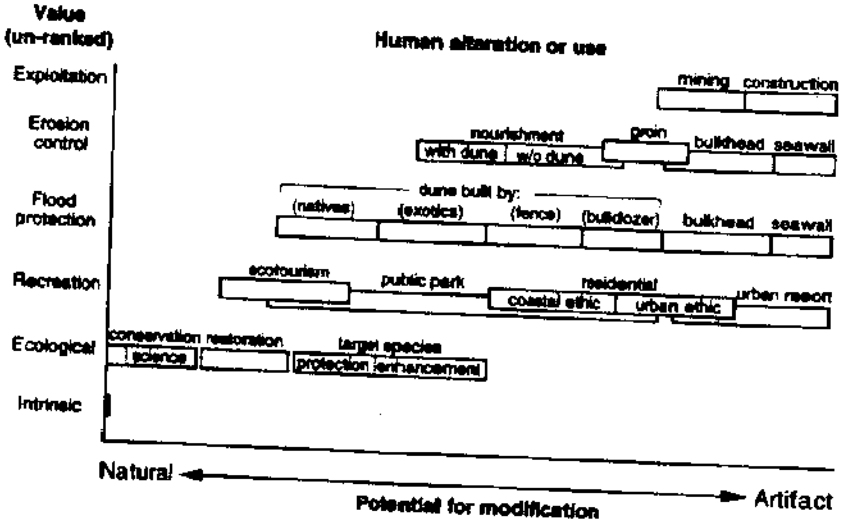

Figure 3. Potential for modification of coastal landscapes from naural to artifact based on perception of values for coastal resources.

those that are most natural. The alterations are presented as mutually exclusive categories in Figure 3 for simplicity of portrayal, although they would not be considered mutually exclusive by many coastal planners and managers. The values in the left column represent nominal data and cannot be ranked quantitatively, but they have been placed in the figure according to the degree to which they contribute to, or enhance, "naturalness." If managers of a segment of the coast wish only to address one value, the most natural of these will be to the left of each row on the diagram. If alternative values are considered, the most natural of these will be on the lowest row considered appropriate.

Intrinsic (inherent or essential) value (Figure 3) refers to the value that a component in nature has in itself. It is not a human-use value, although it is a useful concept to use in developing a management ethic about natural landforms and ecosystems (Nordstrom 1990). Actions taken to protect ecological values vary considerably in their potential for modifying coastal environments. Conservation of ecological resources for scientific study may be distinguished from conservation without scientific study (Figure 3) in that landscapes that are preserved for study of nature are used directly by humans. Restoration results in a less natural landscape than the original that was altered. Protection for target species may be viewed as distinct from enhancement for target species in that protection, if conducted properly, involves less direct alteration of the natural system.

Recreation (Figure 3) can be accommodated with small impact on natural beach and dune environments or it can result in their complete elimination. Ecotourism is one way to incorporate environmental conservation and tourism development in a single strategy (Pearsall 1993). Public parks (national, state, county and municipal) can be developed to accomplish similar goals. Coastal parks vary greatly in emphasis on human and natural features. Some parks may be managed to include urban recreation activities, and beaches and dunes may be altered dramatically to accommodate parking and pedestrian access; other parks may be managed for environmental values, where no recreation facilities are provided and there is no attempt at landscaping, other than use of sand fences in the foredune.

Residents directly alter the characteristics of the shore within the limits of their properties according to personal preference, and they indirectly alter the characteristics of municipally maintained segments by means of their collective participation in community level decisions. The least natural environments occur where residents grade dunes to retain views of the sea, remove sand blown into yards and replace natural vegetation with exotics. These actions are most likely to occur in locations where individual property rights are held in high regard; the owners are seasonal users of the property; or the owners have a landscape ethic that reflects greater familiarity with urban and suburban environments than coastal environments. In many cases, management practices in moderately-developed residential communities may be similar to those used in neighboring intensively developed shorefront communities (coastal resorts), where coastal landforms and vegetation are modified to accommodate mass use. The resulting landscape in these coastal suburbs bears little resemblance to a natural one in topography and vegetation.

Flood protection (Figure 3) involves constructing and maintaining a continuous barrier at prescribed height. The degree to which natural processes are allowed to create and maintain this barrier depends on how critical the need for protection has become. A dune can be constructed by natural aeolian accretion around vegetation where time and space are available, as on nourished shorelines, but bulldozed dunes may be the only landform option in highly erosional areas, where beaches are narrow. The value of a naturally-constructed dune for both flood protection and ecological value argue for combining flood protection and erosion control projects using beach nourishment. Bulkheads are built primarily for backup protection on high-energy coasts that still have a beach; the availability of sand for aeolian transport and the relatively low elevation of bulkheads allows wind-blown sediment to pass over them or bury them, creating the potential for dunes to survive. Seawalls are larger structures that are built as primary protection, and they restrict the landward migration of both the beach and dune and prevent the upland from functioning as part of the dynamic coastal system. There is limited potential for formation of natural landforms where seawalls are the principal form of protection for either flooding or erosion control.

Artificial beach nourishment designed to provide erosion control benefits (Figure 3) has great potential for restoring coastal landscapes, but this potential is usually not realized. Nourishment in many communities is perceived as a means of providing protection to shorefront buildings and providing a recreational platform rather than a means of restoring natural interactions or ecological values. Most nourished beaches are graded into "slabs of sand." In some cases, a low, flat, linear sand dike is constructed on them to provide flood protection. This feature can bear little resemblance to a natural dune.

Groins are artifacts, and the beaches and dunes that accumulate as a result of their placement reflect human impact in terms of their location and shape. The mechanisms of sediment erosion, transport and deposition mimic natural processes, and the landforms created at groins may be considered more natural than bulldozed forms. The perception of groins as structures to be avoided stems from their local effect on the sediment budget, but they have considerable value as habitat, and they do not constitute as great a threat to natural processes as bulkheads and seawalls.

LIMITATIONS OF MANAGEMENT PROGRAMS

Many problems associated with past coastal development projects cannot occur today because of more stringent regulations and increased knowledge about detrimental impacts (Shipman 1993), but there are still many problems that can occur in implementing planning and policy programs that are compatible with maintenance of beaches and dunes (Table 3).

Table 3. Problems of implementing planning and policy programs compatible with maintenance of natural beaches and dunes.

Problems of implementation
- Many parties cause difficulties of coordination and cooperation.
- Modern management is still lacking in some countries.
- Regulations may apply only to new development, not improvements.
- Court-ordered penalties may be too low.
- Illegal activities occur despite regulations.
- Existing environmental management policies may be rescinded or amended.
- Support for rebuilding damaged structures favors property owners.
- Value of shorefront property argues against preventing development.
- Requirement to purchase threatened properties at market value cannot be met.
- Approved initiatives may lack of funding for implementation.

Problems of conflicting goals
- Incompatible or contradictory policies occur in different regulatory agencies.
- Residents and developers have different perception of the resource.
- Uses that eliminate the beach may be considered compatible with a coastal location.
- Water-dependent uses that do not require a beach or dune may have priority.
- Cooperation at local level is often dependent on personalities, not optimal solutions.
- Dredged sediment is lost due to failure to combine navigation and erosion projects.
- Programs may favor public facilities over natural values.
- Individual species rather than landscapes often targets of conservation.
- Sites of geomorphic interest are less significant than sites of ecological interest.

Problems of spatial coverage
- Management may emphasize stability, not sustainability or spatial and temporal flexibility.
- Control zones may not coincide with physiographic units or coastal dynamics.
- Policies may not establish coastal construction setbacks, or setbacks may be too small.
- Degradational activities may be displaced to jurisdictions where there are no controls.

Problems in technical expertise
- Jursdictions usually lack the staff to make technical and scientific evaluations.
- Undeveloped environments may be managed as natural, but they may not be natural.

Problems in timing
- Land-use management may take decades to reveal benefits.
- The process of nourishing a beach can take up to 15 years.
- Waiting for erosion to become an emergency often results in structural solutions.
- Prescribed lifetimes of structures do not reflect their longevity.
- The life of engineering projects exceeds programs of local sponsors.
- Timing of nourishment projects is determined by administrative factors, not beach width.
- Politicians respond readily to emergencies but lose interest in long term projects.
- Long-term study of effects of projects is unappreciated by politicians.

Many of these problems are administrative, but even where environmentally friendly regulations are in place, landform viability may be threatened by the perception that landform mobility is bad or that a less environmentally-compatible value (Figure 3) is more desirable.

Mobility is the key to ensuring the value of coastal environments for ecological values and most human use values, in the sense that the dynamism of beaches and dunes is responsible for their physical characteristics and aesthetic appeal. It is a paradox that stability of beaches becomes the goal once humans attach specific values to them. Attention is often directed toward preserving the inventory of natural features within management units rather than the processes that created them. The mobility is often the characteristic most worthy of conservation, requiring more flexible approaches towards conserving landforms in a dynamic state, based on the significance of landforms for maintaining ecological productivity, preserving rare species and ensuring diversity of habitat (Wanders 1989; Westhoff 1989; Bray and Hooke 1995; Jones *et al.*, 1995).

IMPLICATIONS

Coastal landforms have many values, including intrinsic, ecologic, scientific, recreational, protective, exploitive and positional (i.e. good building sites). Many of the problems in management of coastal landforms stem from a focus on only one or two of these values, resulting in uses that restrict landform size or mobility. Coastal landforms that are perceived as developable properties are landscaped and maintained according to suburban aesthetics (Figure 2). Dunes that are perceived as valuable primarily for their protective qualities are maintained as narrow linear ridges, often planted with a limited number of vegetation species. Beaches that are viewed as recreational platforms rather than resources having intrinsic, ecological, or aesthetic value are graded into flat, featureless surfaces and maintained that way by raking during beach cleaning operations (Figure 2).

Landforms on human altered coasts can be said to evolve, but this evolution follows a progression of construction (or destruction) and maintenance, with changes manifested more in the size of the landform than in its mobility, shape or species diversity as occurs on natural landforms. It would be fruitful and prudent to examine ways to develop or use the shoreline in a manner that maintains or restores natural sediment transfers and accommodates mobility of landforms and their tendency to grow and be altered. Specification of the ways human altered systems differ from natural systems provides perspective on losses and gains associated with development, but it is not likely that an evaluation that simply underscores the ways these systems differ will provide the insight needed to restore natural components of coastal landscapes in developed communities and reinvigorate our sense of coastal heritage. It is important to examine activities in communities that have adopted successful compromise solutions that accommodate human uses and landform mobility and maximize future options for natural environments while retaining an image of the coast that reflects the natural processes that provide its special appeal.

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BEACH REPLENISHMENT AND NAVY HOMEPORTING: ECOLOGICAL IMPLICATIONS OF BEACH REPLENISHMENT IN CALIFORNIA

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ABSTRACT

The San Diego Association of Governments (SANDAG) has developed a Shoreline Preservation Strategy that identifies regional coastal areas with critical shoreline problems caused by the lack of natural sand supply for the beaches. One solution is to use clean sand from dredging to replenish the beaches. A potential source of sand was the Navy Homeporting Project which requires dredging over 7 million cubic yards of sand from the San Diego Bay navigation channel to provide the proper water depths for safe passage of a NIMITZ class aircraft carrier. Chemical and physical analyses indicated that the channel sediments were comprised of clean, beach compatible sands, suitable for use as beach replenishment. Based on these results, the Navy offered the sand to SANDAG for use as beach replenishment at eight onshore (direct placement) and four nearshore locations. In order to obtain the necessary resource agency permits, environmental assessments (EA) were done for each receiver beach to evaluate the potential effects of beach replenishment operations on the following environmental issues: geology and soils, coastal wetlands, water resources, marine biology, land use and recreation, safety and environmental health, aesthetics, utilities, and noise. This paper focuses on: 1) how sensitive marine resources were identified and mapped; 2) how the beach replenishment operations could affect sensitive marine resources at each receiver beach; 3) monitoring requirements; and 4) lessons learned for future beach replenishment projects.

INTRODUCTION

The beaches of San Diego, California are eroding and sand sources to replenish these beaches are no longer available because of damming of rivers and urban development. Couple this with the lack of disposal options for clean, sandy dredged material and it becomes environmentally, economically, and politically beneficial to use suitable dredged material as beach nourishment.

SANDAG has developed a Shoreline Preservation Strategy that identifies regional coastal areas with critical shoreline problems caused by the lack of natural sand supply for the beaches. One solution is to replenish the beaches using clean sand from dredging projects. A potential source of beach replenishment sand was the Navy Homeporting Project. As part of this project, over 7 million cubic yards of clean, beach compatible sand would be dredged from the San Diego Bay navigation channel in order to create the proper water depths for safe passage and berthing of a NIMITZ class aircraft carrier.

Eight beach sites along the San Diego coast (Oceanside, Buccaneer Beach, North and South Carlsbad, Encinitas, Cardiff/Solana Beach, and North and South Torrey Pines) were analyzed for onshore beach replenishment suitability (Figure 1). Beach replenishment suitability was assessed based on the amount of vegetated reef habitat found offshore of the proposed receiver beach. Reef habitat is considered a sensitive marine resource by National Marine Fisheries Service, U.S. Fish and Wildlife Service, and California Department of Fish and Game because it provides habitat for species of algae, fishes, and invertebrates.

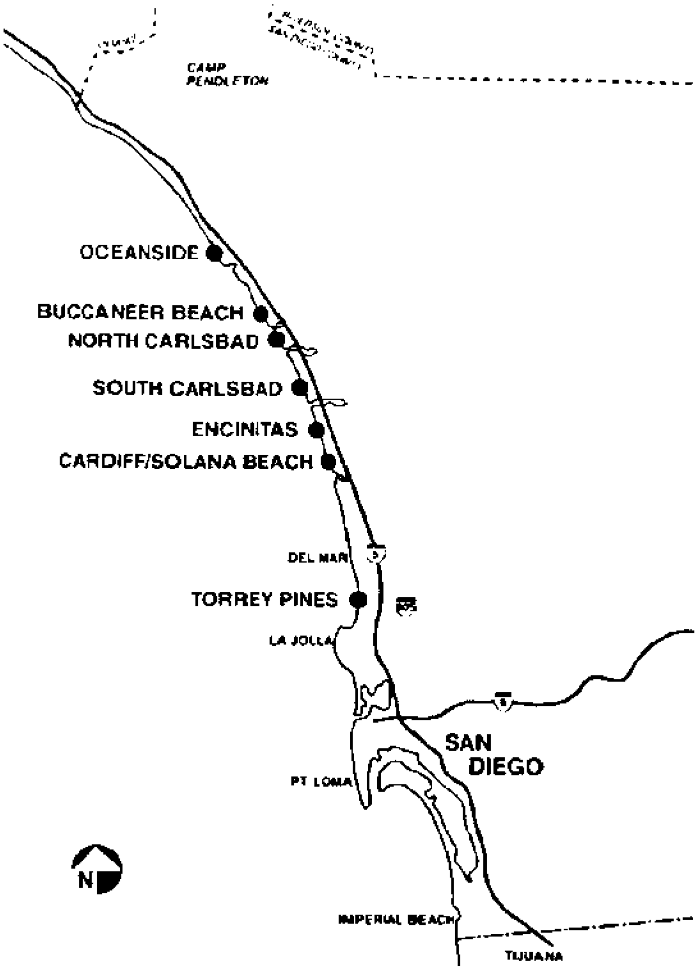

Figure 1. Map of Receiver Beaches

Onshore beach replenishment was defined as sand placement between +2 meters) mean sea level (MSL) and -2 m MSL (FRH 1997). Onshore beach replenishment s not considered an environmentally beneficial or economically viable alternative if shallow subtidal areas that lay directly offshore of the receiver beaches contained nsitive marine resources that would be significantly damaged by beach replenishment tivities.

ETHODS

arine biological field surveys were done to identify and map locations of sensitive arine resources. Sensitive marine resources were defined as rocky intertidal reefs, ntertidal and subtidal reefs that support giant kelp (Macrocystis pyrifera), feather boa elp (Egregia menzesii), surfgrass (Phyllospadix torreyi), and sea palms (Eisenia arborea), nd nearshore reefs with giant kelp. Reefs that support sea fans (Muricea spp.) were also onsidered sensitive habitats because sea fans are indicative of persistent reefs that are not covered by sand.

Each potential disposal area was surveyed from the +2 m MSL tide mark to 350 m offshore (maximum depth of 7 m). The location of sensitive marine species and hard bottom reef areas at each disposal location was determined by a boat-mounted fathometer and diver transects. Fathometer surveys were designed to identify the location of different habitat types (i.e., sand and rock reefs) and also to differentiate between bathymetric features (i.e., flat sandy areas, and low and high relief reefs) within the predetermined disposal footprint at each of the potential receiver beaches. Low relief reefs were defined as reefs that extend less than 1 meter (m) from the sand surface, and high relief reefs were defined as reefs that extend greater than 1 m from the sand surface. When elevated reef areas were identified on the fathometer, divers would make bounce dives (dives of < 5 minutes) in order to determine the elevation of the reefs. Reef location was determined using a Differential Geographic Positioning System (DGPS) and plotted on a map with an accuracy of 2-3 m. Fathometer surveys also enabled marine biologists to cover large areas of the shallow subtidal zone at each receiver beach, identify the locations of the different habitat types and bathymetry of the seafloor; and identify areas where sensitive marine resources may exist.

In areas where sensitive marine resources were identified, divers swam transects to describe the species composition of the reefs, and map the extent of the sensitive marine resources. Divers attached a metered tape to an anchor and swam a predetermined compass heading. Transects were run in a minimum of three directions -- one transect towards the shoreline (east) and two transects parallel to the shoreline (upcoast and downcoast). Qualitative assessments of habitat type and species composition were done from a minimum of eight transects per disposal footprint (Figure 2).

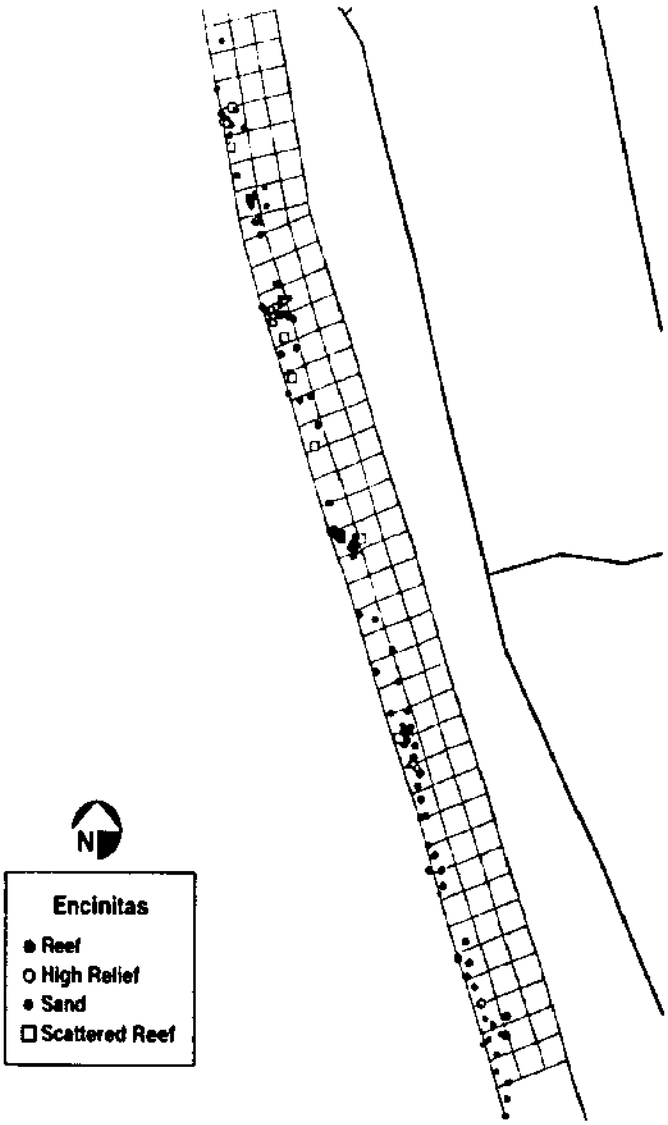

Figure 2. Locations of Sensitive Marine Resources
Offshore of Encinitas, California

Using this methodology, the location, habitat type, and species composition of each reef was mapped and placed into a Geographical Information System (GIS). GIS mapping was used to determine the amount of sensitive marine resources at each receiver site and enabled the sensitive habitat areas to be resurveyed and monitored after the disposal. In addition, the potential for littoral transport of the newly placed sand outside of the disposal area was considered.

RESULTS

There was variability in the presence and composition of sensitive marine resources among the proposed beach replenishment sites (Navy 1997a and 1997b). The potential receiver beach areas were divided into three categories: 1) all sand with no reefs or sensitive marine species present; 2) predominately sand, with some areas of low and high relief reefs in the shallow subtidal zone with some sensitive marine resources; and 3) predominately low and high relief reefs covered with sensitive marine resources.

ALL SAND RECEIVER AREAS

Oceanside, Buccaneer and North Torrey Pines were characterized as all sand habitats devoid of reefs and sensitive marine species. Organisms that live within sandy beach areas have adapted to a continually changing environment including physical factors such as grain size, beach slope, turbidity, wave action, and other physical tolerances that greatly influence species diversity, abundance, and distribution.

Sandy beaches are home to many invertebrates and fishes and can be characterized by the following species. Beach hoppers, isopods, and three species of polychaete worms are commonly found in the upper intertidal zone (Thompson *et al.*, 1993). Sand crabs are common in the middle intertidal zone but move with the tide throughout the intertidal area. Polychaetes, snails, and the bean clam are also found in the middle intertidal zone. Tubicolus polychaete and nemertean worms dominate the lower intertidal area and shallow subtidal zones (Straughan 1982). Patches of sand dollars are also found in the shallow subtidal zones.

Fishes such as the California corbina and barred surfperch are common in shallow subtidal areas, often darting into the surf zone to feed on sand crabs. Other fishes that commonly occur over sandy bottoms include topsmelt, queenfish, spotfin, yellowfin and white croaker, California halibut, shovelnose guitarfish, and round stingray (ACOE 1994).

PREDOMINATELY SAND RECEIVER AREAS

North and South Carlsbad, Cardiff/Solana Beach, and South Torrey Pines receiver areas were characterized by sandy beaches in the intertidal zone, and hard substrata (i.e., low and high relief reefs) interspersed among sand channels in the shallow subtidal zone. The sandy areas were dominated by the same species as the all sand locations. The shallow subtidal zones of these receiver areas had low and high relief reefs that were scattered among sand channels. Reefs were hard substrate (rock or sandstone), elevated above the sand, and provided increased surface area and crevices for species to inhabit. Consequently, the reefs were home to more species than the sandy substrates. Sessile invertebrates and algae attach to the reefs, while the reef crevices provide habitat for fishes and invertebrates.

Vegetated reefs contained species of red (fleshy and coralline), green, and brown algae including feather boa kelp and sea palms. Surfgrass beds were also present on low relief reefs at the receiver beach area. Giant kelp was not found on the shallow subtidal reefs at these locations, but was observed further offshore (> 6 m deep).

Invertebrate diversity is higher on hard substrata and common sessile species observed include mussels, burrowing clams, tube worms (Family Serpulidae), sponges, and bryozoans. Mobile species consisted of lobsters, crabs, sea urchins, sea stars, and gastropods (e.g., snails, limpets, and sea slugs).

Numerous fish species that are important to recreational and commercial fisherman were observed at these receiver sites. Fish diversity and abundance within the shallow subtidal reefs and kelp beds are influenced by the presence of kelp and substrate relief (Cross and Allen 1990). Kelp beds are not important spawning areas for fish but do provide refuge and foraging areas for juveniles and adults (Cross and Allen 1990). California sheephead, garibaldi, blacksmith, rockfish, kelp and sand bass, many species of surfperch (Family Embiotocidae), and opaleye are commonly found near rocky reefs and kelp beds.

PREDOMINATELY LOW AND HIGH RELIEF REEFS

The Encinitas site was the only site that had substantial reef habitat that extended from the upper intertidal zone down to the shallow subtidal. The upper intertidal was characterized by sandy beach and cobble habitats that extended into the middle and lower intertidal zones. Low relief scattered reefs were present in the middle and lower intertidal zones, extending down to the shallow subtidal habitat. And throughout the shallow subtidal zone, low and high relief reef habitats were present. The majority of the low relief reefs were vegetated with patches of surfgrass, while the high relief reefs were vegetated with giant kelp, feather boa kelp, sea palms, and surfgrass (Figure 3). Based

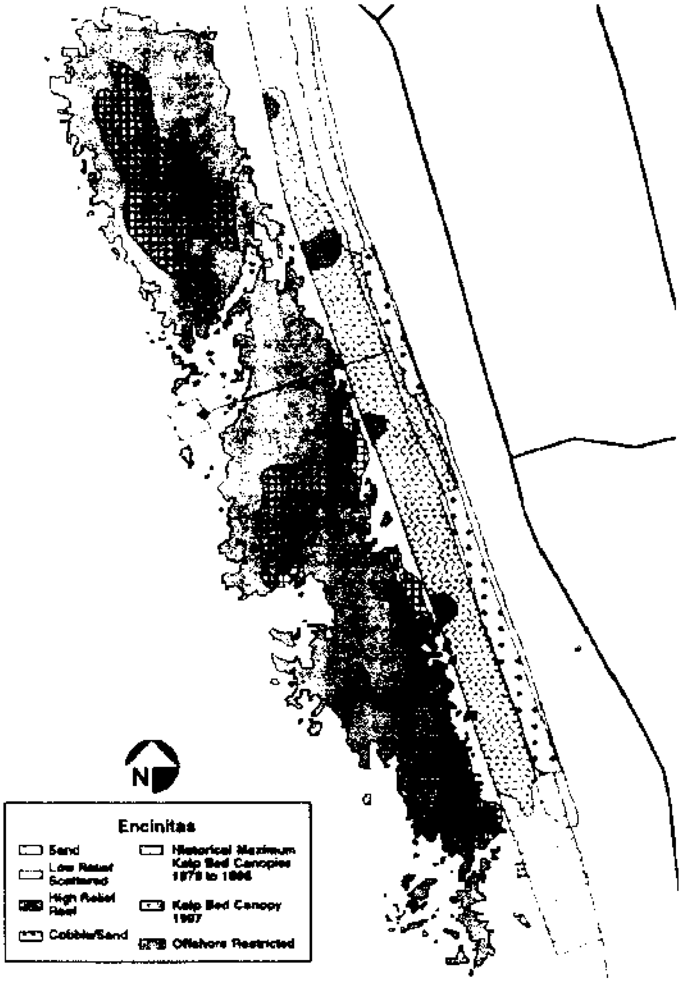

Figure 3 Results of GIS Mapping Offshore of Encinitas, California

on the species observed at Encinitas (i.e., long-lived species that are sensitive to sand burial), the reefs appeared to be perennial and show no signs of being covered by sand. Large stands of giant kelp were also observed offshore.

DISCUSSION

The presence of sensitive marine resources offshore of the disposal site was a major factor in determining impacts. Natural sand movement at San Diego beaches is a seasonal cycle with movement offshore in the winter and onshore in the summer. Sand is also transported downcurrent between beaches. Offshore/onshore sand movement can be as much as 2 m at some beaches (ACOE 1991). Thus, the sand movement of the newly placed sand would become part of the natural sand transport system in the shallow subtidal zone, and could potentially cover and damage well established sensitive marine resources.

This study was designed to identify direct and indirect impacts of beach replenishment and qualify these impacts as permanent or temporary. Direct impacts would occur when biological resources are altered, disturbed, destroyed, or removed during the course of project implementation. Other direct impacts may include the loss of foraging habitat for wildlife species and habitat disturbance that results in unfavorable substrate conditions (i.e., incompatible grain size). Indirect impacts would occur when project related activities affect biological resources later in time or in an area removed in distance. Potential indirect impacts resulting from project implementation would include increased sand transport and silt deposition, which could potentially result in lagoon inlet closure and increased turbidity in the longshore environment. Both direct and indirect impacts can be classified as either temporary or permanent, depending on the duration and significance of the impact. Temporary impacts are considered short-term when impacts on biological resources are reversible over a period of time. Permanent (long-term) impacts would result in the irreversible removal, disturbance, or destruction of biological resources.

Each receiver beach would be permitted by the resource agencies to receive large amounts of sand based on the impact analysis. All beaches, with the exception of Encinitas, were permitted to receive sand onshore as beach replenishment. Encinitas was not permitted for beach replenishment because the shallow subtidal and nearshore areas located offshore of the potential receiver area contained almost 100 percent coverage of reef habitat which supports an extensive amount of sensitive marine resources (Figure 3).

Because no sensitive marine resources were present at Oceanside and Buccaneer beaches, they were permitted to receive sand with no post-discharge monitoring requirements. The other beaches that were considered predominately sand beaches but had reefs and sensitive marine species interspersed or localized offshore of the sand disposal activities were required by the Army Corps of Engineers to have long-term post-discharge monitoring.

Monitoring is scheduled to occur biannually (during spring and fall) until the year 2001. Monitoring will assess changes in abundance and coverage of sensitive marine species. Analysis will be done by plotting the number or percent cover of sensitive species (e.g., giant kelp, feather boa kelp, palm kelp, and sea fans) and total area of sensitive marine resources (e.g., surfgrass and habitat area) on time series graphs to identify long-term trends at each reference and test reef. After the trends are plotted, quantitative assessments of the time series trends and appropriate statistical tests will be used to quantify impacts. Site-specific comparisons to reference area data, temporal changes, relationships to dredging activities, and relationships to other factors such as wave action, sea temperatures, and storm data for each year will also be factored into the trend analysis.

CONCLUSIONS

This project served two important functions. First, it is the first beach replenishment project of it's magnitude and kind in southern California. The project will bring much needed sand to the beaches. The hope is for this project to act as a springboard for future beach replenishment projects and ease the permitting process for future projects. Secondly, the marine environmental assessment mapped and identified marine resources for large areas of the shallow subtidal zone along many beaches in San Diego County. The composition and extent of the resources were unknown prior to this study. Beach replenishment projects are necessary in order to maintain the beaches of San Diego. This study showed, however, that extensive marine resources exist directly offshore of potential receiver sites and these resources will need to be taken into account during the permitting process for future projects.

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CALIFORNIA'S COASTLINE: EL NIÑO, EROSION AND PROTECTION

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INTRODUCTION

While the El Niño concept is a relatively new one to many residents of California, historical records from Peru documenting El Niño events in the equatorial Pacific go back at least 4 centuries (Quinn, *et al.*, 1987). The last major El Niño event affecting California took place in 1982-83 and produced $8 billion in damage worldwide, with $2 billion of this damage in the United States. This event affected the entire coast of California from Del Norte county on the north to San Diego county on the south and produced in excess of $100 million in storm damage during January alone: 27 oceanfront homes and 12 businesses were completely destroyed, 3000 homes and 900 businesses were damaged, and 11 of the 15 coastal counties were declared state and federal disaster areas (Swisher, 1983). Public damage reached nearly $34 million and much of this was concentrated in parks and recreational areas in Los Angeles and San Diego counties. The majority of the private losses (which totaled $46 million) occurred in Santa Cruz, Los Angeles and Orange counties as structural damage to homes. Businesses suffered an additional $16 million in damage (Swisher, 1983).

Why was there so much damage during the 1982-1983 winter? Two factors were important in producing these losses.

- The sea levels along the entire California coast were elevated well above predicted tidal heights, primarily due to thermal expansion of sea water due to the influx of warm water from the equatorial Pacific. On January 27, during the highest spring tides of the year, the largest recorded waves arrived. Sea levels recorded at tide gages in San Diego, Los Angeles and San Francisco ranged from 0.95 to 1.77 feet above predicted and were the highest recorded throughout the entire historic tide gage record at all three sites.
- Nearly all historic coastal storm damage in California has occurred at high tide. A number of storms, accompanied by large waves, struck the coast in the first three months of 1983 and at least seven of these arrived coincident with high tides, further elevated by El Niño conditions. As a result, beaches were eroded, did not recover prior to the arrival of the next storm and high tide, and therefore continued to erode. As a result, storm waves broke closer to structures or on structures and inundated areas normally protected by wide beaches. Waves caused 20-40 feet of dune/bluff recession at Pajaro Dunes, a private oceanfront development in central Monterey Bay. At Del Mar, waves reduced the beach profile by 10-15 vertical feet as sand was transported offshore.

All oceanographic signs throughout the latter part of 1997 indicate that a very significant El Niño event was underway, perhaps the largest of this century. Most would agree, however, that it is impossible in December to predict the impacts of this developing El Niño on coastal California during the subsequent winter months simply because of uncertainties and unknowns: future storm tracks and storm frequency, sea levels, and tide/wave interactions.

California has 1100 miles of shoreline, 950 miles or 86% of which is eroding. The length of the coast has not changed significantly in historic times but the population which utilizes and has developed on the coast continues to increase (Figure 1). At the time of the last major damaging El Niño in 1982-83, the state's population stood at 24.8 million people. At the time of the arrival of the 1997 event, the state's population had increased 29% to 32 million. Eighty percent of these people live within 30 miles of the shoreline and 4 million live within 3 miles of the water's edge.

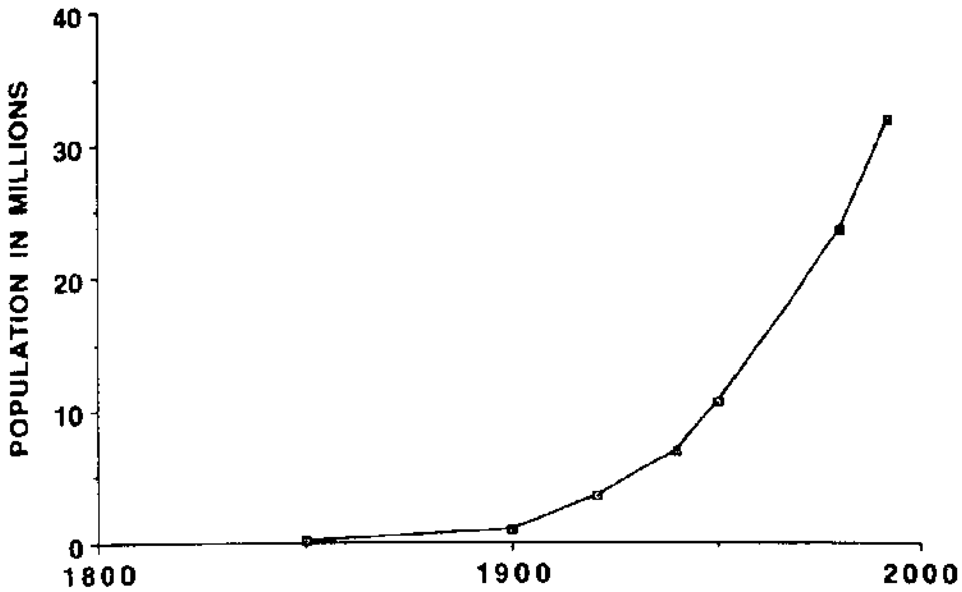


Figure 1 California's increasing population

As a result of topography, climate, availability of water to some degree, and therefore historical development patterns, the coastal population is not evenly distributed throughout California's coastal counties (Griggs, Pepper and Jordan, 1992). Residents in rural Humboldt County have about eight feet of shoreline each, whereas residents of suburban Los Angeles County have less than half an inch. Overall, each resident of the state would have about two inches of coastline if it was accessible, but this is not the case for much of the rugged and inaccessible central and northern coast. In addition, the coastline must be shared with the millions of visitors. To make matters worse, the population of the state is projected to reach 50,000,000 by the year 2020 (California Department of Finance, 1989).

CALIFORNIA'S COASTAL HAZARDS

Coastal geologic hazards in California occur most frequently in the form of shoreline erosion (both bluff and beach) and coastal flooding (both wave impact and inundation). Human interference with coastal processes (such as sand supply and littoral drift) and coastal bluff stability (increased surface runoff, loading, or elevated ground water tables) have exacerbated hazardous conditions in many locations.

The California shoreline has three distinct hazardous geomorphic environments where widespread development has taken place: eroding cliffs or bluffs, the back beach, and coastal dunes. A survey of existing oceanfront public and private structures and infrastructure indicates that the risks of building in these environments were either not recognized or not respected when permits were granted or construction took place. Politics and economics have also played an important role in particular locations (Griggs, Pepper and Jordan, 1992).

ERODING BLUFFS OR CLIFFS

Eroding bluffs and cliffs represent California's most extensive coastal hazard and no area of the state has a monopoly on short-sighted planning in this environment (Figure 2). Because of California's location along an active plate boundary, tectonic uplift of the coastline has produced many square miles of easily developed flat marine terraces. From

Figure 2a. Construction on eroding coastal bluffs: Marin County

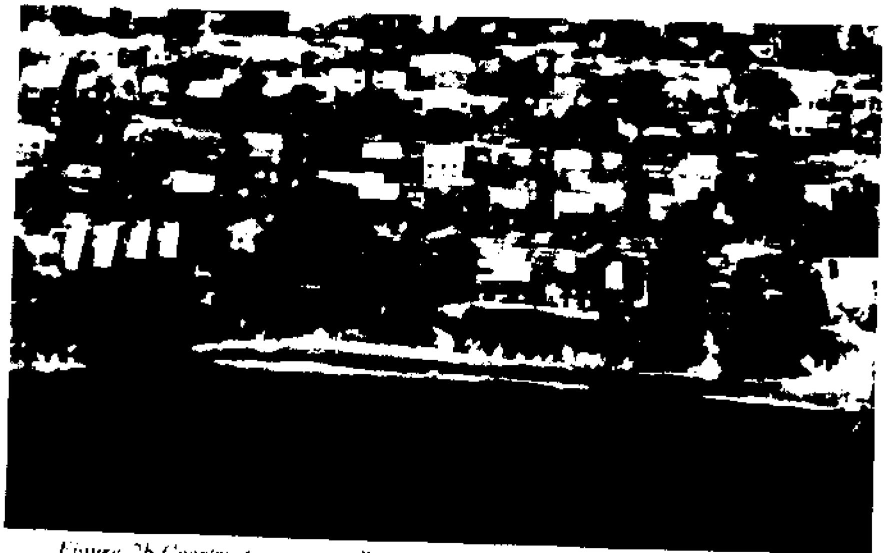


Figure 2b Construction on eroding coastal bluffs: Santa Barbara County

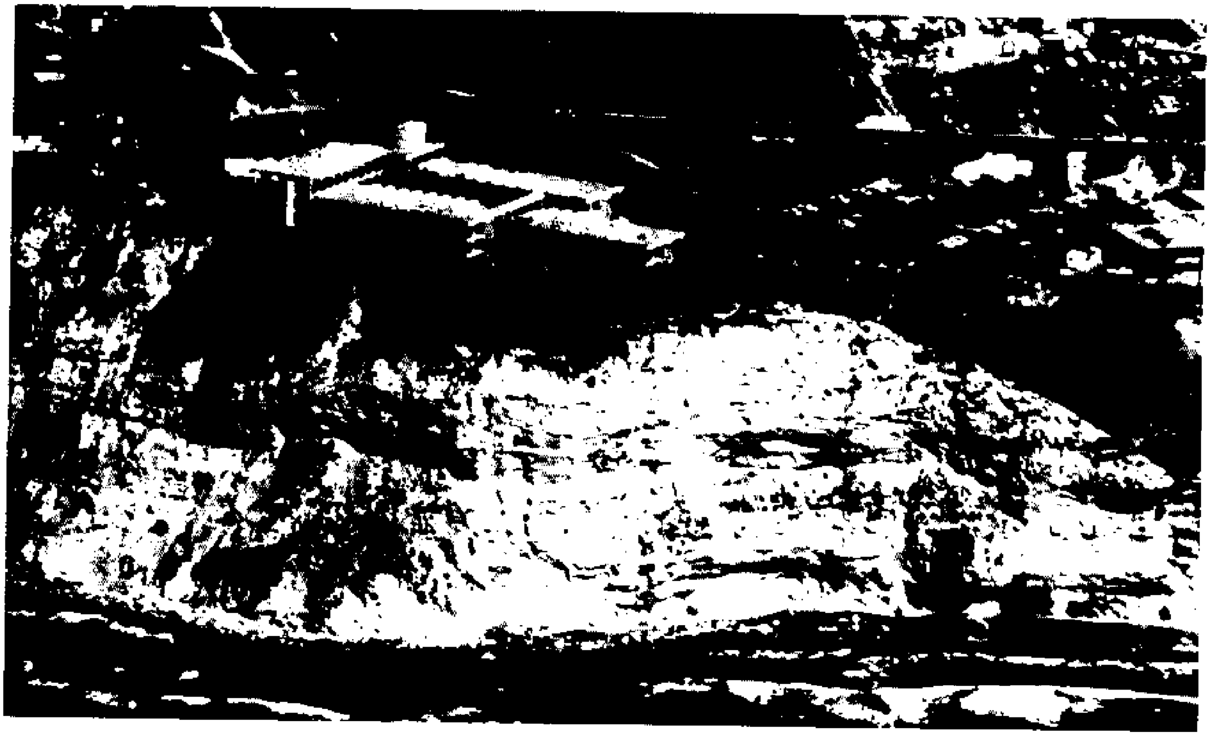


Figure 2c. Construction on eroding coastal bluffs: San Diego County.

Humboldt county in the north to San Diego county in the south, these flat benches have been developed with homes, condominiums, apartments, restaurants and hotels. In most locations, this development has encroached right to the cliff or bluff edge, where views of the ocean are unobstructed and property values are the highest, but where the risks to structures of continuing bluff retreat are the greatest.

Rates of coastal cliff retreat are primarily a function of the interaction of two factors: 1) the resistance of the cliff materials to erosion or failure, and 2) the degree to which the physical processes producing cliff breakdown or failure impact the cliffs. While most coastal bluff erosion is often wave induced, both seismic shaking (Figure 3; Griggs and Scholar, 1997) and terrestrial processes (surface runoff and slumping or sliding) can play important roles, particularly where the cliffs are protected from wave attack. Average

Figure 3 Coastal bluff failure in Daly City from seismic shaking during the 1989 Loma Prieta earthquake.

long term erosion rates along the coast of California range from negligible where crystalline granitic rocks form the coastline (e.g. the Monterey peninsula), to as much as eight feet/year where unconsolidated dune sands form the bluffs (Figure 4). A few inches to a foot/year are typical average rates of cliff retreat in the sedimentary rocks which make up much of California's coast.

Figure 4 Ft. Ord, central Monterey Bay, where unprotected unconsolidated dunes to either side of the rip-rap are eroding at average rates of eight feet/year. Note the lack of a beach in front of the rubble but a beach to either side where there has been no armor.

While qualitative information on coastal bluff retreat is readily available (e.g. old photographs, eroded roads, exposed storm drains and similar structures), accurate rates of shoreline erosion are more difficult to come by. Yet it is these long term rates that are what we should have determined and used in the past, and should be using now, to establish setback lines for any proposed oceanfront construction.

There are a number of methods which have been used to measure rates of coastal cliff erosion, each with their own limitations, costs and benefits, and which need to be understood before indiscriminately using "average" erosion rates. The basis for nearly all of these methods is 1) a set of historical aerial photographs and/or maps which span as long a time period as possible, and 2) a tool or technique for measuring the change in shoreline or cliff edge position over the time span of the photos and/or maps.

The climatic representativeness and length of time covered by the air photos or maps, the experience and skill of the interpreter, scale and resolution or clarity of the photos, the degree of photographic distortion and any efforts to rectify or correct for the distortion, the ability to locate and measure from reference points in the photographs to the cliff edge, and the technique used to perform the measurements and rectification, all affect the data derived and the erosion rates which are ultimately determined.

Unfortunately, long term average annual cliff erosion rates have not been accurately determined for most of the shoreline of California. There are a number of reasons for this lack of data: 1) relatively few investigators have taken the time to determine accurate long term measurements, 2) failure to obtain the long term photographic or map base needed for such measurements, 3) most studies have been relatively short term or have covered very small areas, 4) a lack of trained investigators, and 5) a lack of the equipment or tools for either checking the photos for distortion, correcting the photographs or for making accurate erosion rate measurements.

In addition to the lack of erosion rate measurements at the time when most coastal construction took place, there are several additional factors which appear to have been responsible for the nearly continuous development of the eroding oceanfront cliff and bluff tops of most of southern California's coastline and portions of the central state's coast: 1) the very high value of coastal real estate and therefore the political and economic consequences of denying building permits, 2) allowing infilling of existing developments, or using the stringline approach, 3) the lack of local or statewide policies or adherence to existing policies on setbacks, and 4) the assumption in some municipalities that armor would be allowed or even required as a means for halting shoreline erosion at the time when oceanfront structures became threatened.

Coastal communities from one end of the state to the other have lost entire oceanfront streets, utility lines, lots of record and homes through the ongoing process of cliff erosion over the last century (Figure 5). New developments are still being proposed on eroding or unstable blufftops and small, older weekend beach cottages are still being torn down

Figure 5. Cliff retreat endangering structures in Capitola, northern Monterey Bay. All of the structures in this photograph have now been either removed or demolished as erosion has progressed.

and replaced by larger new homes. When the California Coastal Act was passed in 1972, coastal hazard issues were not as obvious as they have become since 1978. During the last two decades winter storm wave attack has been more severe along the coast than it had been in the previous three decades. Although statewide guidelines were established in the Act for determining the stability of coastal bluffs and potential development, there is no statewide policy establishing safe setback distances from cliff or bluff edges. As a result, some jurisdictions use a predetermined, fixed setback, although these vary from as little as 10 to as much as 320 feet. Others employ a cliff retreat rate (supposedly site specific) applicable over a specific time period or structural lifespan, most commonly a 50-year period (Griggs, Pepper and Jordan, 1992).

BACK-BEACH CONSTRUCTION

Virtually all California beaches undergo striking seasonal changes in width in response to changing wave climate. Due to longer term fluctuations in wave climate, the year to year seasonal changes may be more or less extreme. For many of the same reasons that Californians have so intensively developed the coastal bluffs, they have also built directly on the beach in many locations. Throughout much of coastal California, homes have been built either directly on concrete slabs or above the sand on wooden pilings or concrete piers. Much of the over $150 million in storm damage along the California coast since 1978 occurred when storm waves combined with high tides washed through such beachfront developments as Stinson Beach, Rio del Mar, Malibu, Del Mar, Oceanside, and Imperial Beach.

Damage during the 1983 El Niño winter included undermining of shallow pilings or piers so that homes collapsed onto the beach (Figure 6). Homes on low pilings were also uplifted by waves at high tide and smashed through pilings as they fell. In addition,

Figure 6 Collapse of a home built on shallow pilings on Rio del Mar Beach, Monterey Bay, during the winter of 1983 due to beach scour

waves overtopped low protective seawalls and either damaged or destroyed the homefronts facing the sea (Figure 7). Nonstructural damage such as losses of decks, beach stairways, patios, yards and landscaping was widespread in these oceanfront locations. Events of this sort will not occur with any regularity or predictability, but the fact that these homes are built directly on or over beach sand is clear evidence of the wave inundation which can be expected at these locations.

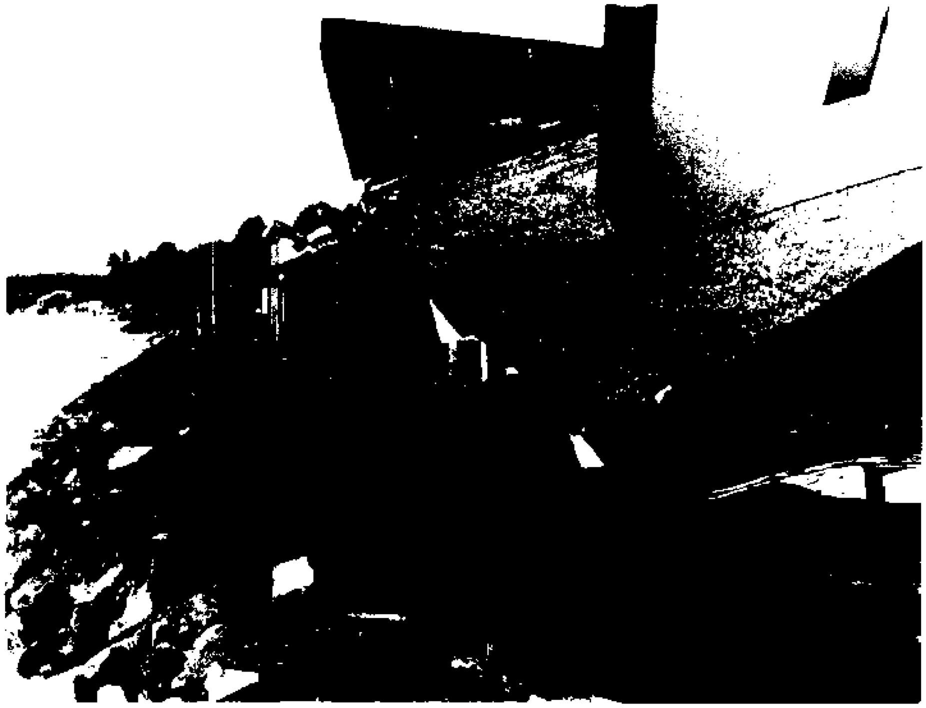


Figure 7 Destruction of walls of oceanfront beach homes at Aptos Seascape, Santa Cruz County, due to wave overtopping of revetment in 1983.

The storm damage to these beachfront areas during recent years is clear testimony that either 1) these risks were not adequately evaluated, 2) that the hazards of living on the beach were disregarded in the planning process, or 3) that the coastal armor was going to provide complete protection from wave attack. A partial explanation for these shortcomings lies in: 1) the relatively infrequent simultaneous occurrence of very high tides and large waves such as occurred in 1983; 2) the tendency for people to have short "disaster memories" and buy or rebuild after damaging storms; 3) the large number of immigrants to California in recent years who have not experienced coastal hazards; and 4) the moderate climate and storm history of the 30 year period from 1946 to 1976, an era of rapid population growth and intense coastal development in California.

Many homes and protective structures were approved and built by planners, engineers, and contractors without firsthand experience with a winter such as 1983, and therefore, suffered from inadequate setbacks, elevation, or design considerations (i.e. wave runup elevation, scour depth, etc.). Additionally, there is commonly a significant time lag between the collection of coastal process or hazard data by scientists and utilization of the data by engineers, such that many structures have been underdesigned through utilizing outdated, generic, or cookbook design criteria or physical process information.

Despite California's intense beach level development, neither the California Coastal Act nor the subsequent Interpretive Guidelines specifically recognized the hazards of direct wave impact or wave/tidal inundation (coastal flooding) on beach level structures (Griggs, Pepper and Jordan, 1991; 1992). As a result, policies at the state's local government level on beach front construction vary widely. Most of the state's coastal jurisdictions have adopted FEMA Flood Insurance Rate Maps which delineate zones that are subject to different degrees or elevations of coastal flooding. Although these maps were originally developed for insurance purposes, they now have regulatory status. The lack of state guidelines for safe development at beach-level has led to continued development and reconstruction in hazardous locations.

COASTAL SAND DUNES

In contrast to the east and Gulf coasts of the United States, where coastal barrier islands and dunes are the typical land forms, the California coasts is characterized by coastal mountains, terraces, cliffs and bluffs, with only occasional lowlands where dunes have developed. Dune fields have formed in the central and southern Monterey Bay area, Pismo Beach, Oxnard, and along portions of the Los Angeles and Orange county coasts.

Sand dunes form an important buffer to wave action and also provide an extra reservoir of sand for beaches during periods of extreme wave attack. During calmer weather periods the beaches will widen, and where dunes have formed, they will build outward and upward. During winters of extreme waves, these same dunes may be severely eroded simply because they consist of unconsolidated sand and offer little resistance to wave attack. In some areas of California, the dune vegetation, which stabilizes the sand, has been removed as construction has taken place, in some cases, directly on the frontal dune. The frontal dune is an active land form which migrates over time, and centuries of experience on the east coast indicates this is not a wise place for any permanent construction.

Nonetheless, the frontal dune in central Monterey Bay was intensively developed with homes and condominiums in the late 1960's and 1970's; the waves during the 1983

El Niño cut back the beach and dune and threatened dozens of ocean front homes (Figure 8). Only the emergency emplacement of rip rap saved the homes from collapse as the foredune was eroded. A permanent revetment was subsequently built at cost of approximately $5 million along a mile of dune frontage.

Figure 8. Erosion at the unconsolidated dunes at the Pajaro Dunes, central Monterey Bay, development during the 1983 winter.

RESPONDING TO SHORELINE EROSION

The storm damage over the past 20 years along the California coast has brought the issue of oceanfront construction, coastal hazards and El Niño to the forefront, here and elsewhere. When the tide is high, waves are large, cliff or dune retreat and beach erosion can occur rapidly, threatening, damaging or destroying property, homes, and public infrastructure which have been safe for years. The 1983 losses were a reminder and wake up call for many.

As the 1997 El Niño develops, many are wondering what to expect. As has been stated earlier, predictions for the winter are impossible due to the number of uncertainties, but the historic record does provide some insight. A careful analysis of the history of coastal storm damage along the Monterey Bay coastline of central California since 1910, indicates that 46 of the 61 damaging storms (or 75%) during this time period occurred during El Niño events (Curt Storlazzi, University of California, Santa Cruz, unpublished research). This strong correlation indicates that coastal storm damage is much more likely during El Niño years.

Coastal erosion or retreat is a natural ongoing process, intensified during El Niño years, which has only become a problem because we have built permanent structures in areas that are prone to erosion or wave impact. Beaches, dunes, low bluffs, or high cliffs are all temporary features that will continually be shaped or altered by wave forces. Although cliff retreat or beach erosion does not necessarily occur with regularity, all of our knowledge and experience from the past indicate that much of the coastline is constantly changing, some areas slowly, others more rapidly. The more rapid or frequent the changes, the greater the potential impact on any structures we build in this environment. Unfortunately, many homes and other improvements were built literally within a stone's throw of the waves, and herein lies the problem. The Pacific Ocean is 10,000 miles wide and not too concerned about 100 yards of shoreline at the edges. In California and elsewhere around the country, however, we have built right at the edge. Where we have made that decision, there are going to be some inevitable and expensive consequences.

OPTIONS IN AREAS UNDERGOING RETREAT

There are several options for property owners, whether public or private, for areas or structures threatened by coastal erosion. These include retreat or structural relocation (Griggs, 1995), nourishment, and armoring. While some buildings have been relocated or demolished, and beach nourishment has taken place as a byproduct of harbor dredging, over the past 50 years the typical response to shoreline erosion in California has been armoring, or the construction of seawalls and revetments. As of 1990, an astonishing 130 miles or 12% of the entire shoreline of the state had been armored, with the more populated central and southern California counties more extensively armored than the north coast (Figures 9 and 10). In the 14 year period from 1971 to 1985, primarily as a

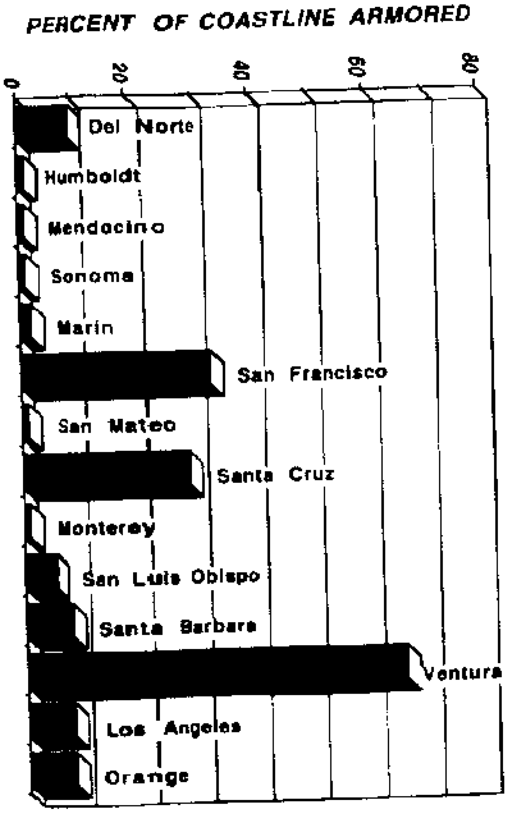


Figure 9. Percentage of California's coastal counties which were armored by 1989

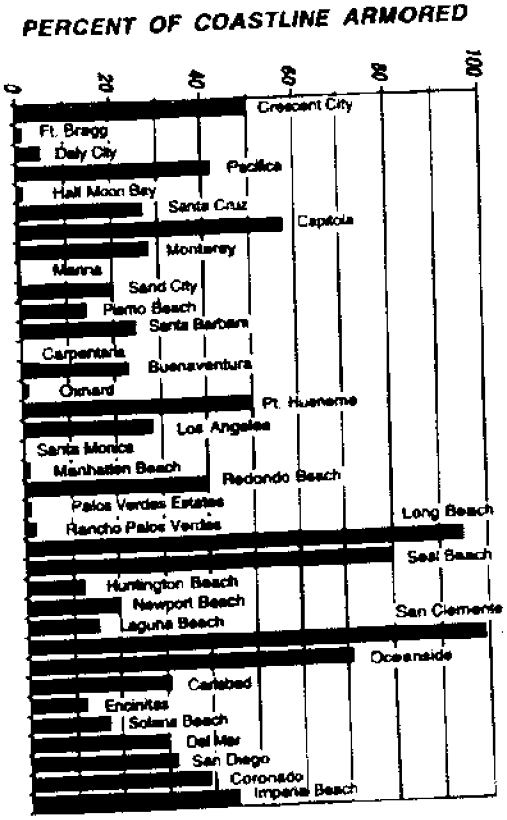


Figure 10. Percentage of California's coastal cities which were armored by 1989.

response to coastal storm damage during the El Niño events of 1978 and 1983, the length of the state's shoreline armored increased 220% or by an additional 58.5 miles (Figure 11). At present day costs of $1000 to over $3000/front foot, a mile of armor or seawall

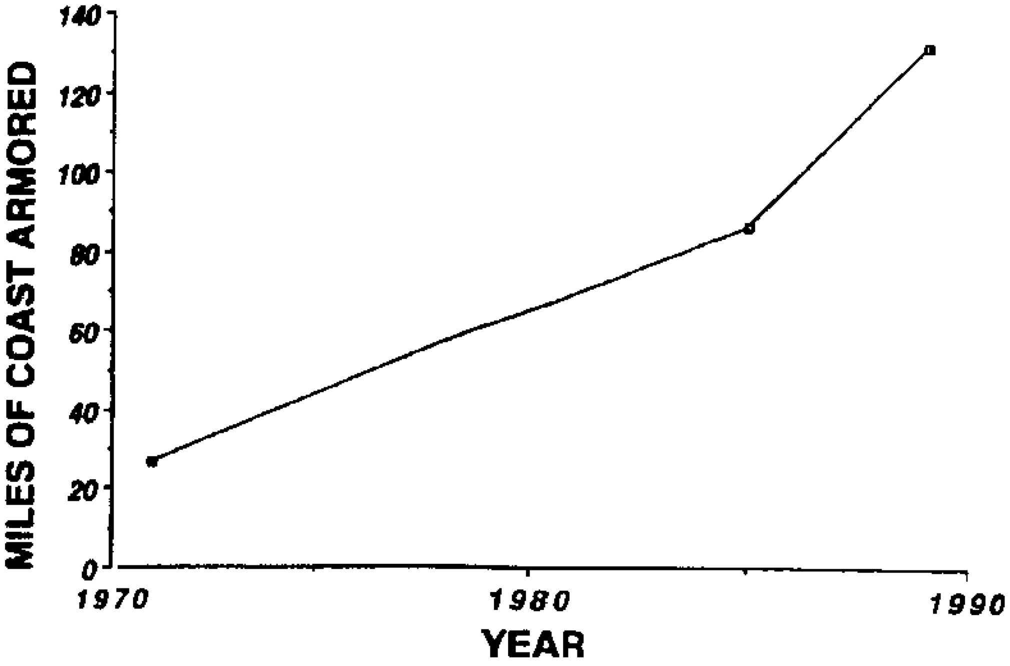


Figure 11. Increase in percent of the entire coastline of California which has been armored.

today has a price tag of $5 million to over $15 million, a cost often covered in the past either by state or federal funds or by insurance settlements. In either case, it is more often than not the general public who has ultimately paid for many coastal protection structures.

Coastal protection structures in California have a mixed record of success (Fulton-Bennett and Griggs, 1986). There are structures which were built almost 70 years ago which are still intact and functioning (Figure 12), others which have not survived a single winter, and still others which have been repeatedly destroyed and rebuilt (Figure 13). Because many of these seawalls and revetments were built following the damaging

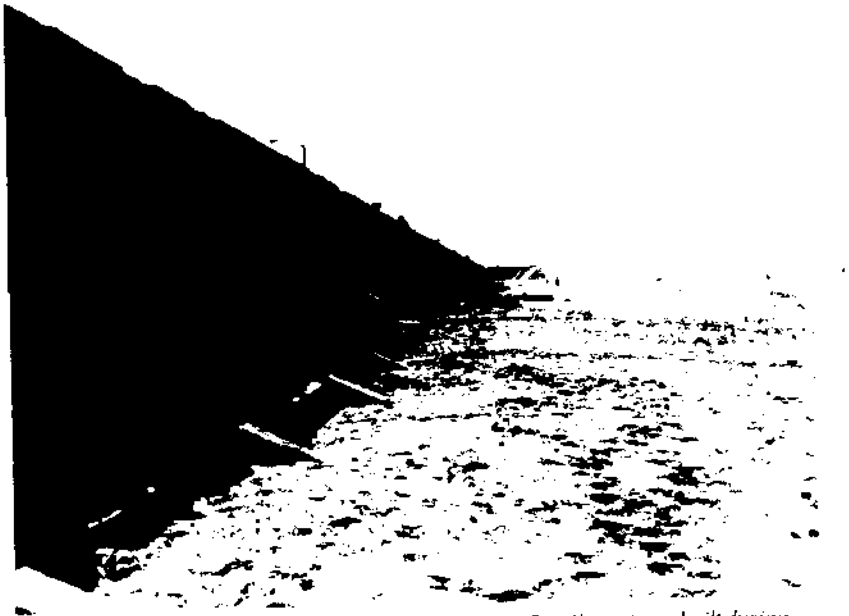


Figure 12. The massive O'Shaugnessy seawall in San Francisco, built during the Great Depression in 1929 is still intact.

Figure 13 This timber bulkhead at Seacliff State Beach has been damaged or destroyed and rebuilt 8 times in the last 70 years. Note remnants of earlier walls in the surf zone

storms of 1983, they have not yet experienced severe wave conditions. The 1983 waves and high tides destroyed many of the weaker existing seawalls such that those that did survive and the newer ones built since, presumably will have a higher survival and success rate during future storms.

While coastal armoring has some very real benefits, it is also accompanied by some very clear impacts (Griggs, *et al.*, 1997). Unfortunately, with coasts retreating along all the nation's shorelines, and with considerable private property threatened, the plea for halting "coastal erosion" has been confused and been combined or interchanged with a plea to halt "beach erosion". There is a very important difference and distinction between protecting or preserving the beach, and armoring the shoreline to halt cliff or bluff retreat, but this is rarely made clear.

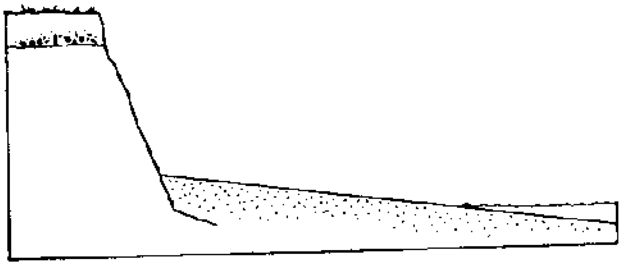
Historically, seawalls have been built to protect buildings and not beaches (Pilkey, 1988). Because seawalls have been built at locations where shoreline recession or beach erosion is already evident, a connection has often been made between the two. As a result, the question has been asked: Do seawalls cause beach erosion? This question is now a concern to coastal engineers and geologists, as well as to planners who must make decisions as to whether a proposed protective structure should be constructed. While the issue of impacts in different coastal environments is still not completely resolved and therefore an area of active research, planners and decision makers are becoming more hesitant to grant permits or authorize money for structures.

Any large engineering structure placed on a beach is going to interact to some degree with the physical processes operating in this high energy environment. Without question, the construction of the numerous jetties and breakwaters along the Atlantic, Gulf and Pacific coastlines of the United States have produced significant shoreline change. The very reasons for building these structures is to alter the physical processes, such that protected and stabilized channel entrances or safe harbors were created. Rip-rap revetments, and seawalls are similarly built to alter or mitigate wave impact on the shoreline.

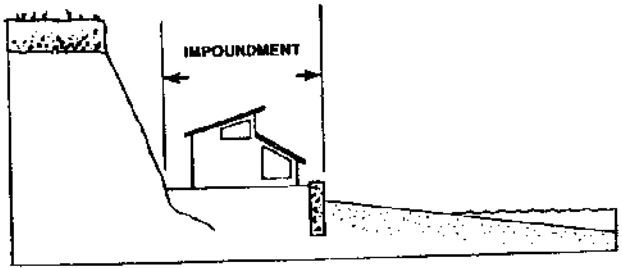
The impacts of seawalls or revetments on beaches are becoming clearer as a result of field studies in recent years and need to be understood and considered before additional armoring plans or projects are developed and approved. These impacts are threefold (Griggs, *et al.*, 1997):

- Impoundment or Placement Loss: This effect is the most straightforward and predictable. When a structure is built seaward of the base of the bluff, cliff, or dune, well out on the beach profile, a given amount of beach is covered (Figure 14). Thus the effect is immediate beach loss; the extent of the loss being a function of how far seaward and alongshore the structure extends. Along the margin of northern Monterey Bay, California, for example, seawalls were built 100 to 250 feet seaward of the base of the bluff in order to allow homes to be built on the back beach. As a result, from Beach Drive in Rio Del

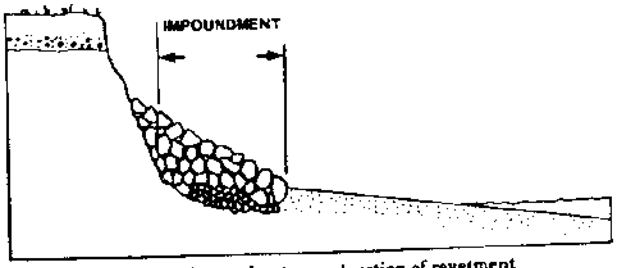
Figure 1. Examples of beach loss through placement of protective structures.



(A) Beach without any coastal protection structures.



(B) Beach impoundment due to construction of seawall and home.



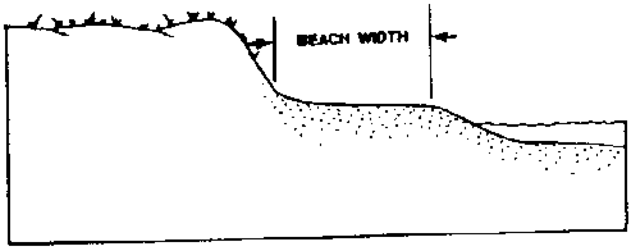
(C) Beach impoundment due to construction of revetment

Figure 14. Examples of beach loss through placement of protective structures

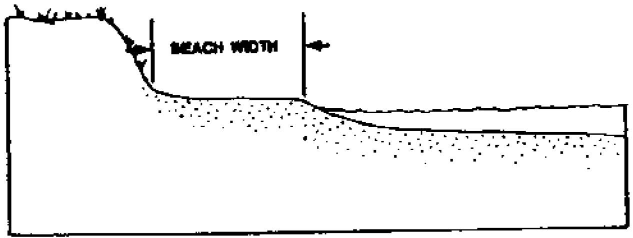
Mar to Via Gaviota in Aptos Seascape, 100 to 250 feet of beach was permanently lost along one mile of coastline.

When a narrow vertical seawall is built against the base of a bluff or dune, however, there is essentially no placement loss. On the other hand, where a revetment is constructed to protect a bluff, it may reach a height of 20 feet or more, and extend seaward at a 1.5:1 or 2:1 slope, thus displacing or covering 30 to 40 ft of beach (Figure 4). Placement loss can easily be determined for any proposed revetment if the cross-sectional and alongshore dimensions are known.

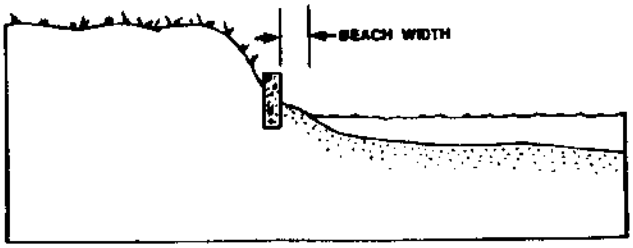
- Passive Erosion: Whenever a hard structure is built along a shoreline undergoing long-term net erosion, the shoreline will eventually migrate landward beyond the structure (Figure 15). The effect of this migration will be the gradual loss of beach in front of the



(A) Initial shoreline profile showing beach width.



(B) Shoreline profile after sea level rise and associated dune or bluff erosion. Although shoreline has migrated landward, beach width remains the same.



(C) Shoreline profile following sea level rise where seawall has fixed shoreline position. Note reduced beach width.

Fig. 15 Example of beach loss through passive erosion following placement of a seawall.

seawall or revetment as the water deepens and the shoreface profile moves landward. This process is designated as passive erosion and appears to be the process which has been documented along many of the barrier islands of the Atlantic coast. As barrier island shorelines erode and migrate, threatening homes and property, seawalls are often constructed for protection. As landward migration of the unprotected portions of the islands continues, in part due to sea level rise, the beach profile also migrates landward, resulting in beach loss in those locations where the shoreline has been fixed by a hard structure (Tait and Griggs, 1990). Passive erosion has also been documented in the Monterey Bay area (Figure 4) where large amounts of rock have been placed to protect a blufftop building on a military base. While a beach is present on either side of the rubble wall, the sand is now underwater in front of the rock and the beach has disappeared. This process of passive erosion appears to be a generally agreed upon result of fixing the position of the shoreline on an otherwise eroding stretch of coast, and is independent of the type of seawall constructed.

Thus, "protecting the shoreline" where it refers to armoring an eroding cliff or bluff, does not "preserve the beach" and in fact, with continuing coastal retreat and/or sea level rise, protecting the shoreline will lead to loss of the beach.

- Active Erosion: The ability or potential for a seawall or revetment to induce or accelerate erosion has been the source of most of the controversy over the past decade regarding the impacts of seawalls on beaches. Although different scientific opinions have been put forward regarding the impacts of these structures on adjacent beaches, there has, until recently, been a lack of field data with which to resolve the conflicting claims.

In an effort to resolve the issues of impacts due to active erosion, we initiated a program of field monitoring in northern Monterey Bay in 1986 with funding from the Engineering Performance of Coastal Structures Research Unit of the Coastal Engineering Research Center. Beach profiles were surveyed at several different seawalls as well as at adjacent control (unarmored) beaches over an eight year period. The objectives were to document the impacts of seawalls on the beach during the seasonal erosion/accretion cycle and to identify any long-term trends. The following conclusions from this work are based on the study of a beach which undergoes significant seasonal changes, but is not undergoing any net retreat over the 8 year study period, and also a shoreline characterized by ~300,000 cubic yards/year of littoral drift (Griggs, *et al.*, 1997).

A number of consistent beach changes related to the seawalls studied were recognized during the long term monitoring. During the transition from summer to winter beach state, the berm is cut back preferentially in front of the seawalls relative to the adjacent unarmored beaches. Once the berm has retreated landward of the seawall, there are no significant differences between the beaches fronting the wall and those from the adjacent control beach. Repeated surveys and comparisons at both an impermeable vertical seawall and a sloping revetment indicate little consistent difference in profile response due to differences in permeability. Either the apparent differences in permeability of the two structures are not significant to wave reflection, or the importance of reflected wave energy to beach scour needs reconsideration.

Scour was often observed at the downcoast end of each structure as a result of wave reflection from the end section of the seawall. The extent of scour appears to be controlled by end-section or return wall orientation, the angle of wave approach, and wave height and period. Surveys of the spring and summer accretionary phase indicate that the berm advances seaward on the control beach until it reaches the seawall. At that point, a berm begins to form in front of the seawall and subsequent accretion occurs uniformly on both beaches. Thus, while the winter erosional phase is influenced to some degree by the presence of a seawall, this is not the case for the berm rebuilding phase.

Of perhaps greatest significance, at this location, is the comparison of time-averaged winter and summer beach profiles for the seawall-backed and control beaches (Griggs, *et al.*, 1997). Comparison reveals no distinguishable differences between the winter profile for the seawall and control beaches and the summer profile for these same beaches.

A PLAN FOR ACTION AT THE STATE LEVEL

The storm damage, both during El Niño and non-El Niño winters of the past two decades, indicates that significant changes are needed in how we approach and deal with coastal hazards and the continuing pressure to develop in oceanfront areas of California. The past inconsistencies among local governments and state agencies who have responsibilities to regulate development indicate the lack of a guiding direction and the heavy influence of local economics and politics.

Through a process of hazard recognition and evaluation, followed by a standardized set of avoidance, mitigation or hazard reduction policies, the private and public losses from future shoreline erosion, El Niño and storm impact and sea level rise can be significantly reduced (Griggs, Pepper and Jordan, 1991). The objective is to reduce the number of people, as well as dwellings, structures, and utilities, both public and private, directly exposed to the hazards of both shoreline erosion and wave impact and inundation. The model of the Alquist-Priolo program, which established Special Studies Zones along California's active faults is an appropriate one to follow for the coastline.

The modest funding required to implement an Alquist-Priolo type program along the shoreline would have a high benefit:cost ratio. Initial investigations would establish the general hazard zones which would then be delineated on official state maps. Any development or significant changes in land use proposed within these areas at the local government (private or public) or state level would require complete geologic hazard investigations, report review by an independent qualified professionals, and appropriate setbacks and mitigation measures where appropriate.

The reduction of both risk exposure and public and private economic losses from geologic hazards in the coastal zone are objectives which need to be realized. The Coastal Act as well as the subsequent Interpretive Guidelines focused on what were deemed to be the critical issues of the time but were deficient in treating geologic hazards. Although some local governments have been effective in dealing with these issues, there are often inherent political and economic constraints at the local level which hinder effective land use regulation. A state level mandate, parallel to the Alquist-Priolo program, which provides a consistent, efficient, and streamlined approach for land use regulation in hazardous coastal areas can accomplish those objectives.

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CHARGE-COUPLED-DEVICE (CCD) DIGITAL VIDEO STUDIES OF BEACH WIDTH, BLUFF EROSION, AND SHORELINE GEOMORPHOLOGY

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ABSTRACT

Charge-Coupled-Device (CCD) video digital imagery exhibits a potential for rapid and inexpensive beach-width and bluff-erosion monitoring as well as reconnaissance of geomorphology and seismic structures.

Examples from La Jolla to Oceanside, along the Southern California coastline, show that water and damp sand absorb the near-infrared wavelengths, causing these materials to appear darker than normal. This facilitates accurate (± 2 ft) mapping of the wetted bound, a frequently used reference line in detecting changes in beach width over time.

A digital mosaic developed from our CCD data of La Jolla Bay reveals previously unrecognized seismic structures exposed on the abrasion platform. These features are related to the active Rose Canyon fault zone and analogous to other shear zones cutting the sea cliffs north of La Jolla. The CCD images help to recognize landslide hazards within these shear zones.

Under certain circumstance, CCD video is more time and cost efficient than traditional aerial photo collection. The system is compact, adaptable, and can be flown on different aircraft and quickly configured for natural disaster assessment after storms, tsunamis, earthquakes, floods, and volcanic eruptions.

INTRODUCTION

Methods used to measure beach width, monitor coastal bluff erosion, and study shoreline geomorphology have included comparison of maps and photographs, traditional survey methods, and interpretation of recorded observations. In searching for a more effective approach, we collected data with a CCD integrated with a super VHS video camera and recorder mounted on a light airplane. This setup made it possible to collect data at rapid rates with low costs.

BACKGROUND

During 1996, the San Diego Association of Governments (SANDAG) showed interest in obtaining long-term data on the stability of the San Diego County coastline. The U.S. Army Corps of Engineers had surveyed the coastline and established beach profiling points (U.S. Army Corps of Engineers, Los Angeles District, 1991), and SANDAG had periodically commissioned traditional aerial surveys from the international border to

Camp Pendleton in Oceanside (Figure 1). Sometime had elapsed, however, since the last collection and assessment of data, and Coastal Consultants sought to demonstrate how new methods could be used to fill this data gap.

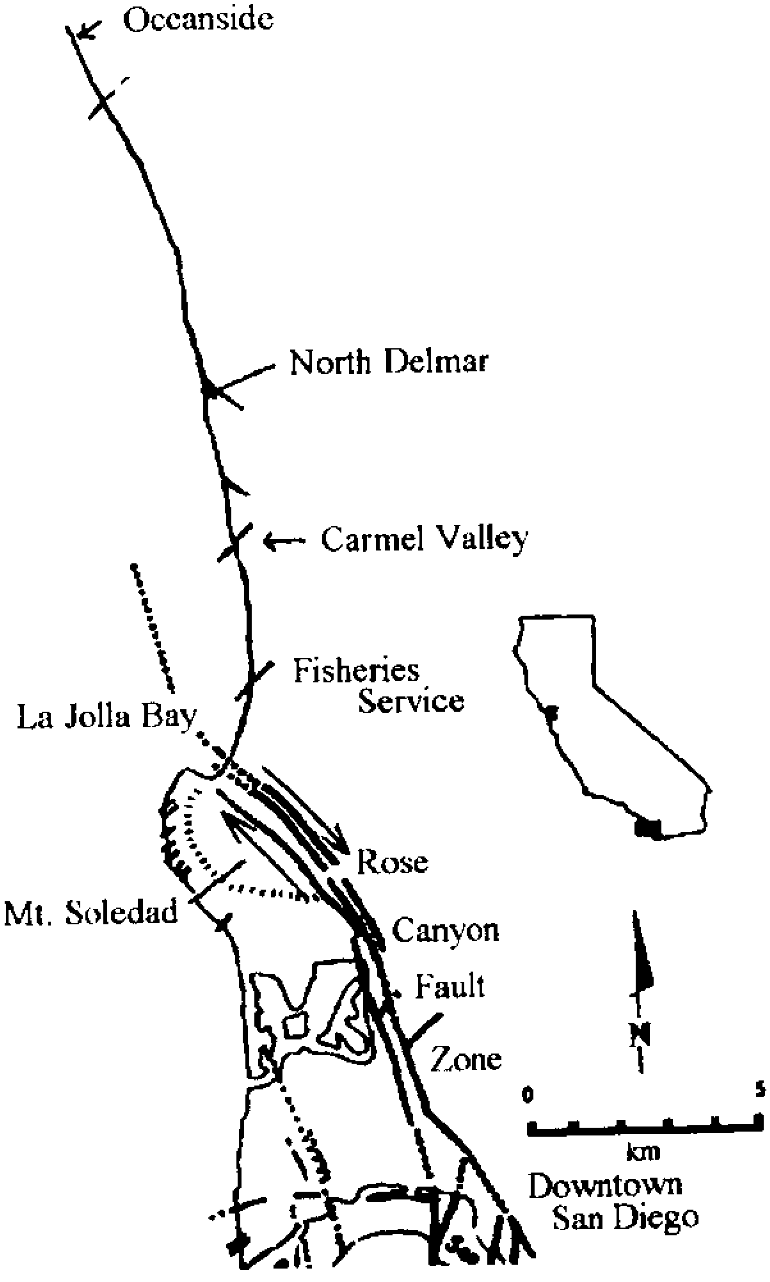

Figure 1. North San Diego County California Coastline

Coastal Consultants also sought to monitor rates of bluff erosion, landslide activity, and catastrophic meteorological events and recognize geomorphology and seismic structures associated with the active Rose Canyon fault zone (RCFZ). The RCFZ joins the Newport-Inglewood fault zone offshore from Oceanside and trends from SW Los Angeles through San Diego Bay and possibly into Mexico (Fischer and Mills, 1991), yet its seismic structures are not well documented or understood.

With the goal of developing a competitive method to replace traditional color/infrared (IR) aerial photography studies, we mounted a low-cost CCD video camera made by Xybion Electronic Systems Corporation with a SVHS recorder on a light aircraft modified to carry the camera. For data preparation and analysis, we selected Earth Resources Mapper (ER Mapper), an image-processing software.

The first flight during the early fall 1996 coincided with a period of maximum on-shore accretion of sand and a maximum monthly low tide.

LOCATION AND GEOLOGIC OVERVIEW

Data collection covered the immediate coastline from La Jolla north to Oceanside. La Jolla Bay is cut by the RCFZ, estimated to be capable of a M 6 to M 7 earthquake (Lindvall, Rockwell, and Lindvall, 1990). Prominent right-lateral movement is responsible for the formation of La Jolla Bay and a left-hand restraining bend is compressing and uplifting nearby Mt. Soledad.

Southwest of the fault zone, rock outcrops are Cretaceous sandstones and conglomerates (Kennedy, 1975). Rocks northeast of the RCFZ and extending past Oceanside are Eocene mudstones, siltstones, and sandstones. These Eocene rocks were wave-abraded during eustatic sea-level stillstands and tectonically uplifted as a flight of marine terraces (Kern and Rockwell, 1992). Below the ocean, this morphology continues as a flight of submerged marine terraces separated by low-relief, paleo-sea cliffs (Emery, 1958).

The beach and near-shore sands rest on the Holocene terrace, the present-day abrasion platform. In many instances, sand loss to the deeper submerged terraces has exposed the abrasion platform or left it covered with cobbles. Water and wave erosion, fault-controlled erosion, landsliding, and tectonic movement have deformed the cliffs, bluffs, and terraces above the abrasion platform, which are intermittently separated by small estuarine river mouths.

METHODS

Image Collection

Xybion's rapid gating, monochromatic CCD video camera, mounted on a light airplane, recorded imagery in wavelengths from 400 to 900 nanometers. The camera collects 30 images per second with digital RS-170 output captured on SVHS tape. The small footprint obtained is a result of lens focal length, altitude, and an effort to maximize resolution. The camera was mounted on the airplane wheel strut and experienced a lot of vibration; therefore, higher resolutions than shown in the examples are expected if the camera is mounted inside the plane.

Image collection was monitored in real time, and this showed that the gusting off-shore winds were pushing the aircraft off course. This real-time information made it possible to re-fly immediately those portions of the shoreline not covered and thus avoid the necessity of making later compensatory flights. Real-time annotation of video images with time and GPS (satellite) position data is also possible. Since the San Diego coast line already has plenty of ground control points, GPS was not used.

Image Processing and Analysis

Super VHS playback screened the data, allowing for identification of portions of the coastline of interest to be placed on a PC via a video capture board, GrabIt. GrabIt has the capability to present 6 images at once and allows the user to capture the frames of interest at resolutions of 1440 x 960 lines. Captured images were stored in computer TGA files and then imported into ER Mapper. Image processing was used to enhance wet/dry contrast and structural features affecting bluff erosion. A number of photo-mosaics were also developed by stitching multiple frames together to cover selected areas of interest.

Although we chose not to do so at the time, measurements could be made by scaling the imagery from shoreline and backshore landmarks; scaling from known distances from survey points and maps; and by rubber sheeting the images to base maps. Beach width comparisons can be accomplished by picking common locations on imagery collected during different time frames; rubber sheeting these images will permit direct overlay for change comparison.

RESULTS AND DISCUSSION

North Del Mar Beach

The North Del Mar beach imagery reflects the wetted bound, a reference line frequently used in detecting changes in beach width (Figure 2). Water and damp sand absorb near

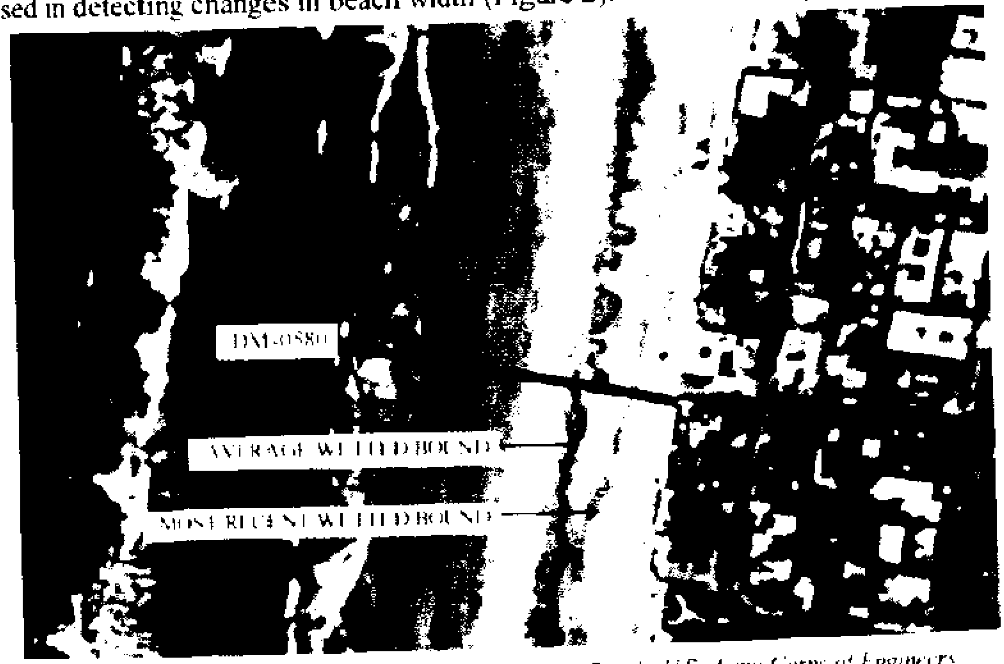

Figure 2 CCD SI Video Image of North Del Mar Beach: U.S. Army Corps of Engineers Beach Profile Range Number DM-0850. Image Acquired 10/23/96, 2:20 PM High Tide at 7:48 AM, Low Tide at 2:02 PM

infrared wavelengths, causing these materials to appear darker than normal. For groundtruthing, a beach profile from one of the U.S. Army Corp benchmarks was developed through traditional, non-imagery methods (Figure 3).

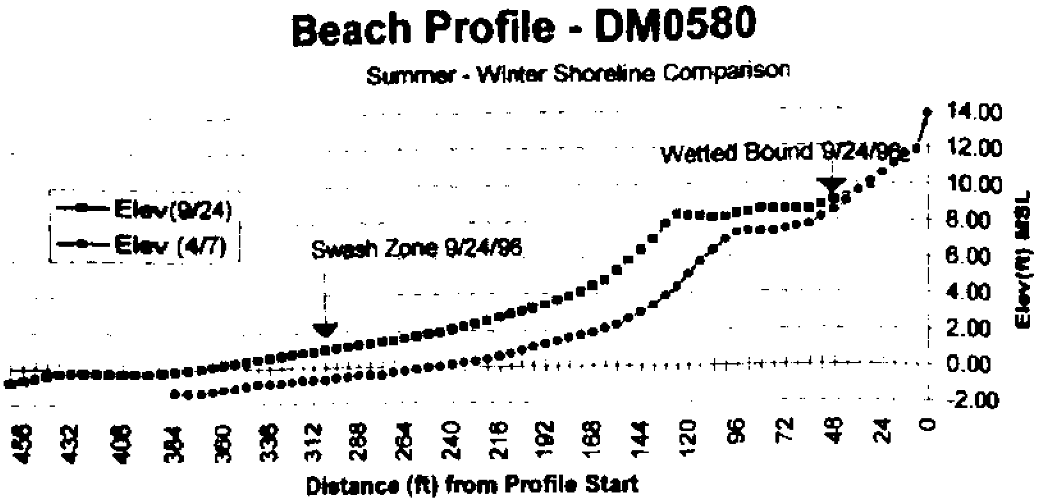

Figure 3 Example of Del Mar Fall and Spring Beach Profiles. Wetted Bound for 9/24/96 Is Inland of the Average Wetted Bound, Which Is Represented By the Top of the Berm

The distinctive wavy dark band running along the beach face correlates with the crest of the berm and, in this instance, with the seasonal average wetted bound. Afternoon sunlight, reflected off the steep, seaward berm face causes it to appear as a whitish band running parallel to the average wetted bound. In addition, the berm face is comprised of coarser, lighter-colored, more quartz-rich sands relative to sands deposited seaward of the berm face and along the berm crest.

The most recent wetted bound (deposited during the morning hours prior to the survey) is inland of the average wetted bound. The accuracy with which these features may be recorded is estimated at better than ± 2 ft. The CCD imagery shows that both the seasonal and the recent wetted bound can be mapped easily and accurately using near-infrared monochromatic video.

La Jolla Bay and the Rose Canyon Fault Zone

A digital mosaic, made from CCD video imagery of La Jolla Bay, was computer enhanced to show the shallow ocean floor and geologic structures with criss-crossing lineations

(Figure 4). Lineations paralleling the NW trend of the RCFZ represent the intersection of the abrasion platform with SW-dipping Cretaceous sedimentary beds. Other lineations, trending in a NE direction, represent previously unrecognized shear zones cutting the sedimentary beds.

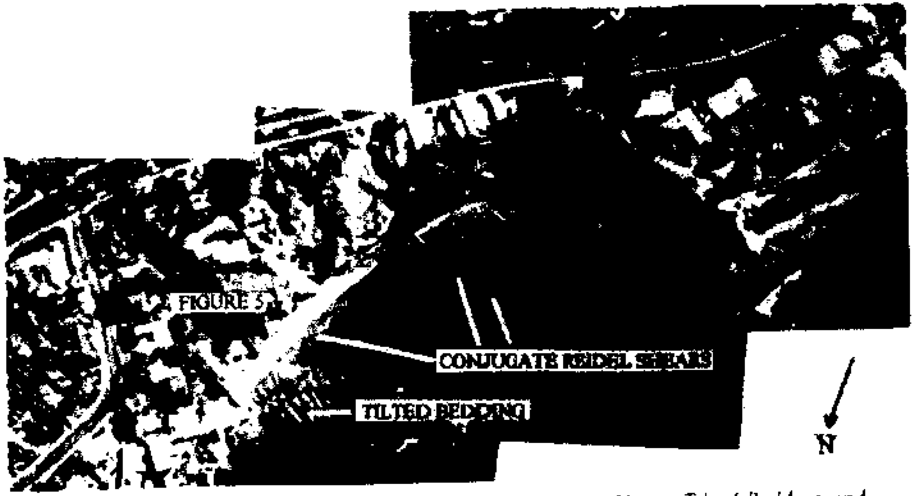

Figure 4. CCD Video Mosaic of La Jolla Bay. Image Shows Tilted Bedding and Seismic Structures Crisscrossing the Abrasion Platform

Following the 1996 CCD video survey, La Jolla Bay was surveyed a second time using hand-held, 35 mm cameras. These higher resolution images, in addition to ground evidence, are being used to alert the public about seismic and slope stability hazards. Ground studies at the point where these NE-lineations intersect with the bluffs along the beach suggest both lateral and thrust shearing (Figure 5). The resulting complicated

Figure 5. Photomosaic along Trend of Previously Unrecognized NE-Striking Shear Zone Showing Evidence of Lateral Movement and Compression. For Location, See Figure 4.

shear systems are often involved in modern ground instability. For example, Coastal Consultants has become aware of a private residence experiencing repeated landsliding problems at the intersection of the sea cliff with a NE trending shear zone.

Research approximately one mile north of the RCFZ, at the cliff base beneath the Southwest National Marine Fisheries Science Center (SWMF), has revealed a set of strike-slip conjugate thrust faults trending in a NE to E-W direction (Rindell, 1993 and 1994). A second shear zone of prominent NE-striking, possibly left-lateral shears is also reported along the base of the SWMF. The CCD imagery depicts strong NE lineations crossing the upper cliff face. In its ongoing geologic investigation for the National Oceanographic and Atmospheric Administration, Coastal Consultants has come to recognize that the lineations in the upper cliff are also NE-lateral shears. Their presence in the upper cliff helps determine the rate and morphology of landsliding at the SWMF.

The CCD imagery highlights several other NE trending shear zones similar to those of La Jolla Bay and the SWMF. These cut the seacliffs at numerous locations between La Jolla and Oceanside. The most prominent zones cut through the North Torrey Pines sea cliffs and the mouth of Carmel Valley (Rindell, 1994) and the town of Carlsbad (Schlemon and Kuhn, 1997; Kuhn, 1997).

Recent published fieldwork suggests a probability of co-seismic activity along some of these shear zones if the RCFZ were to rupture. The trends of these lineations are analogous to features predicted by a right-lateral strain ellipse oriented N50W, the strike of the Rose Canyon fault as it enters La Jolla Bay (Figure 6). (For a discussion of the strain ellipse, see Christie-Blick and Biddle, 1985, or Davis and Reynolds, 1996.) The strain ellipse suggests that these NE-trending lineations are zones of left-lateral conjugate

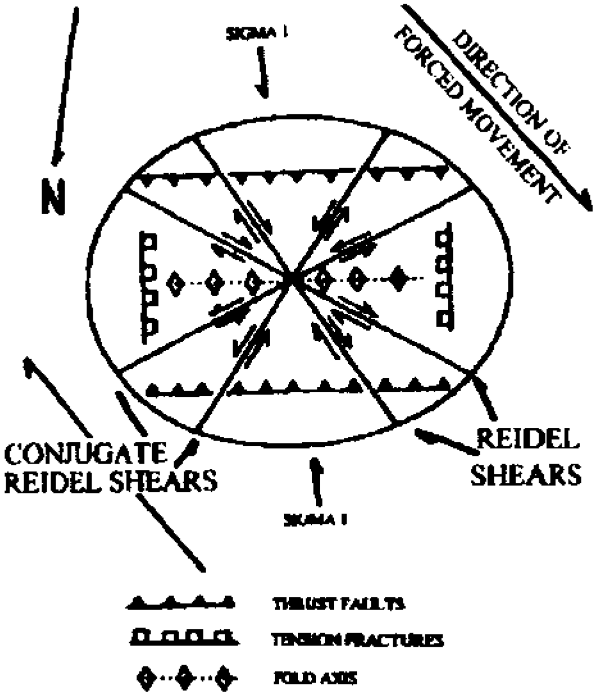

Figure 6. Strain Ellipse Rotated To N50W, the Average Strike of the Rose Canyon Fault Zone as It Bends Around Mount Soledad.

Reidel shears, part of a complex system of shears associated with the RCFZ. The California Division of Mines and Geology, however, has mapped these features as normal faults (Bulletin 200). The suggestion that these are lateral shears and not normal faults is a new concept.

While the possibility of seismic hazard poised by the NE shears is being debated, the adverse effects these features have on sea cliff stability and landslide hazard is becoming painfully real to numerous coastal landholders. The CCD imagery of Torrey Pines, La Jolla Bay, and other studies indicate that bluff erosion and landsliding occur more rapidly where the shoreline bluffs have been weakened by faulting and associated fractures.

The recognition of the previously unknown La Jolla Bay seismic structures and other NE-trending features shows that CCD video imagery can be used for quick and inexpensive preliminary geomorphologic surveys over long stretches of shoreline.

SUMMARY AND CONCLUSIONS

CCD video digital imagery exhibits a potential for rapid and inexpensive beach-width and bluff erosion monitoring as well as reconnaissance of geomorphic and seismic structures. Although film generally has higher resolution, video provides more images (30 images/second) and has lower initial acquisition costs than aerial photography. By eliminating film development, prints, and digitization, video is more time and cost efficient.

The resulting low-cost imagery is available for immediate interpretation. Coupled with hand-held photography and ground truthing, it can provide significant flexibility while remaining within the client's budget. The final product can be tailored for use with vector data and stored as files compatible with most government and private-agency GIS systems.

The video collection system is compact, adaptable, and can be flown on different aircraft and quickly configured for natural-disaster assessment after major storms, tsunamis, earthquakes, floods, and volcanic eruptions.

ACKNOWLEDGMENTS

This project was performed gratis. We thank Xybion Electronic Systems Corporation for their expertise and cameras and Earth Resources Mapper for the use of their mapping software. The images shown in this paper were taken with a Xybion camera duct-taped to the wheel strut of a Cessna 172. Having found out that this is illegal in the USA, we thank SanLo Aerial Surveys for modifying their airplane.

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POCKET BEACHES OF CALIFORNIA SEDIMENT TRANSPORT ALONG A ROCKY COASTLINE

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ABSTRACT

The California coast was examined using atlases, maps, aerial photographs, and during field observations. From this examination we determined that pocket beaches with adjacent rocky headlands make up approximately 28 % of California's coastline. Pocket beaches, like all beaches in California, are an important state resource. Sediment transport processes on pocket beaches in California are poorly understood due to lack of research. A study of two adjoining pocket beaches, located at the mouth of Yellow Bank Creek on the Santa Cruz County coastline, is being conducted by the University of California, Santa Cruz Coastal Geology Laboratory and the U.S. Geological Survey's Coastal and Marine Group. This intensive onshore and offshore study investigates sediment transport processes within a pocket beach system and along a rocky, pocket beach coastline.

INTRODUCTION

Both wide sandy beaches and small pocket beaches are an important resource to the state of California in several ways. Economically, beaches generate billions of dollars each year in direct state revenues from coastal tourism and recreation. Beaches protect the coastline against erosion by absorbing wave energy, the primary agent of coastal erosion. Additionally, beaches contribute to the high quality of life enjoyed by Californians, 80 % of whom live within 30 miles of the coast. Over the last 50 years, population and development along the California coast has increased dramatically. Ironically, approximately 86 % of the California coast is undergoing irreversible erosion posing a significant geologic hazard. In response to the threat of property loss and damage from coastal erosion, extensive armoring has been emplaced along the California coast. Although armoring structures have been successful in slowing the processes of cliff or bluff erosion, in many cases beaches are lost either by passive erosion or by the presence of armoring structures such as rip rap. An understanding of the basic sediment transport processes on pocket beaches and along their coastlines is necessary for sound and effective management of these coastal areas.

California's Coastline

When we think of beaches we often picture long stretches of wide sandy beach which are a common feature along the California coastline. California's wide sandy beaches comprise approximately 32 % of the State's 1100 miles of coast. Nearly 40 % of the California coast has no sandy beach at all, but is instead composed of narrow rocky shelves with offshore rocks, sea stacks, rocky cliffs with sea caves or arches, or near vertical wave cut cliffs. The remaining 28 %, or 308 miles, of the California coastline, contains pocket beaches with adjacent rocky headlands (Fig. 1).

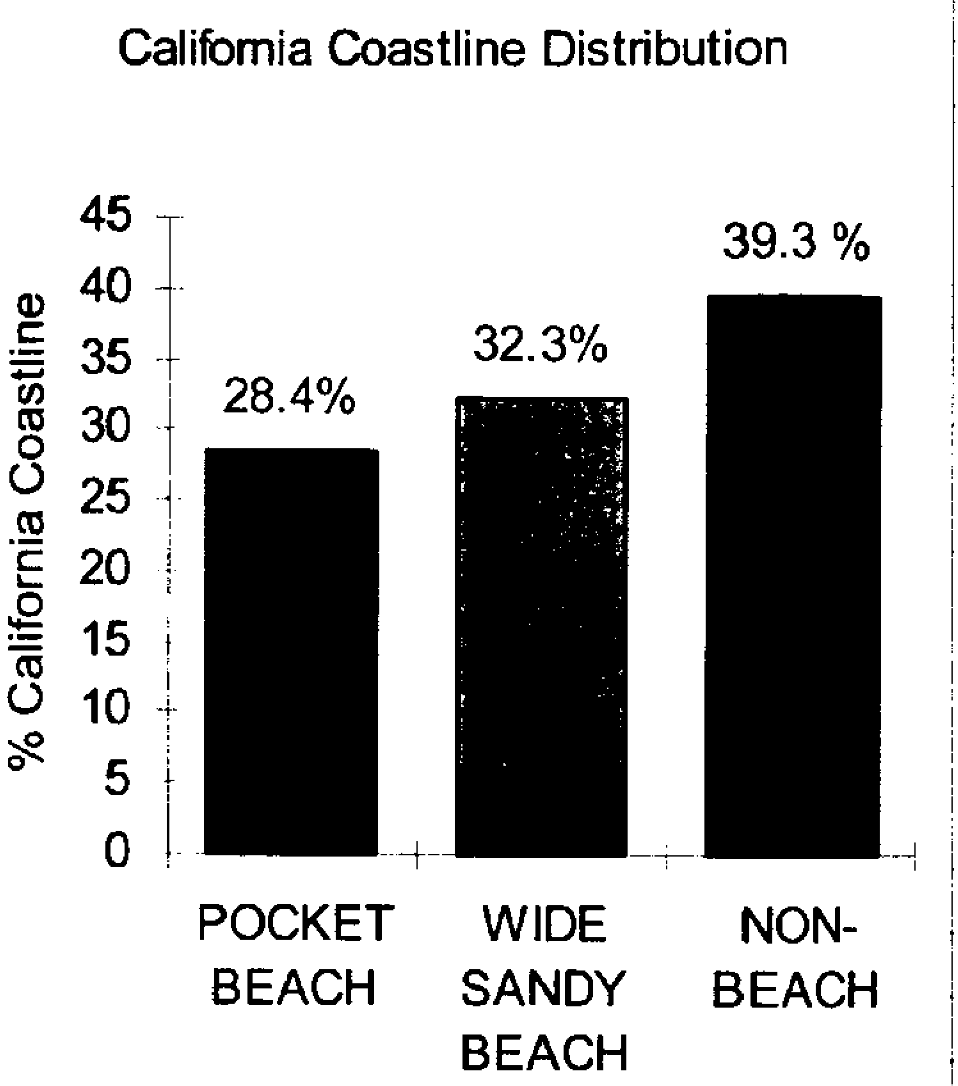

Figure 1. Distribution of California's coastline by type: pocket beach coast, wide sandy beach coast, or non-beach coast.

Although they are a more dominant coastal feature in the central and northern parts of the state, pocket beaches are found in every coastal county in California (Fig. 2). These beaches are not confined to remote or undeveloped areas, they make up many state park beaches, residential area beaches, and popular tourist destinations. Coastal management in California includes management of pocket beaches. Understanding the distinct sediment transport processes of pocket beaches and how they differ from those processes along continuous, sandy coastlines, is necessary for effective management of the shoreline.

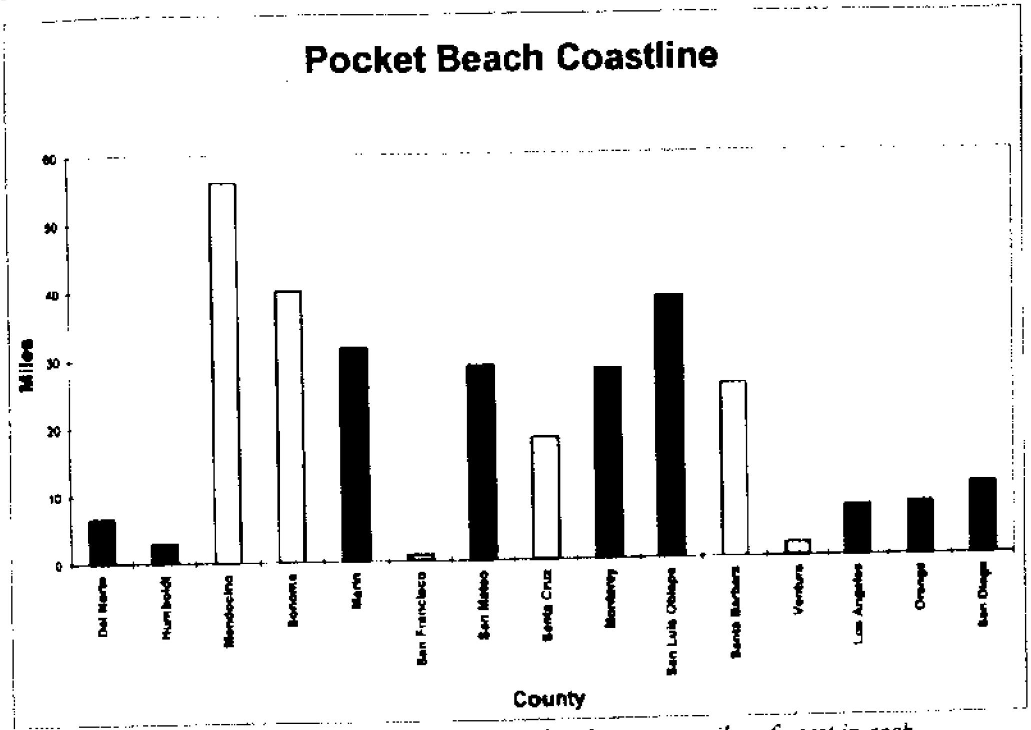

Figure 2. California's pocket beach coastline by county; miles of coast in each county containing pocket beaches with adjacent rocky headlands.

Description and Distribution of Pocket Beaches in California

Pocket beaches found in California were examined and identified using coastal atlases (Habel and Armstrong, 1977), maps, aerial photographs, and during field investigations. From this examination we determined that pocket beaches are small, usually no more than one mile long, indentations in the coastline and are bounded by headlands (Fig. 3). Pocket beaches typically occur where coastal streams have cut into the cliff or bluff forming a "pocket" in the coastline where sediment is deposited. Offshore of many pocket beaches are sediment-filled relict or paleo-stream channels (Anima *et al.*, 1996). These ancient stream beds were formed during the last glacial period when sea level was about 120 meters lower and coastal streams incised the continental shelf forming the channels which today are submerged. Along the California coastline, pocket beaches are backed by a variety of geologic environments such as high wave cut cliffs with active slides, low bluffs, coastal stream deltas, marshes, flood plains, and various dune environments.

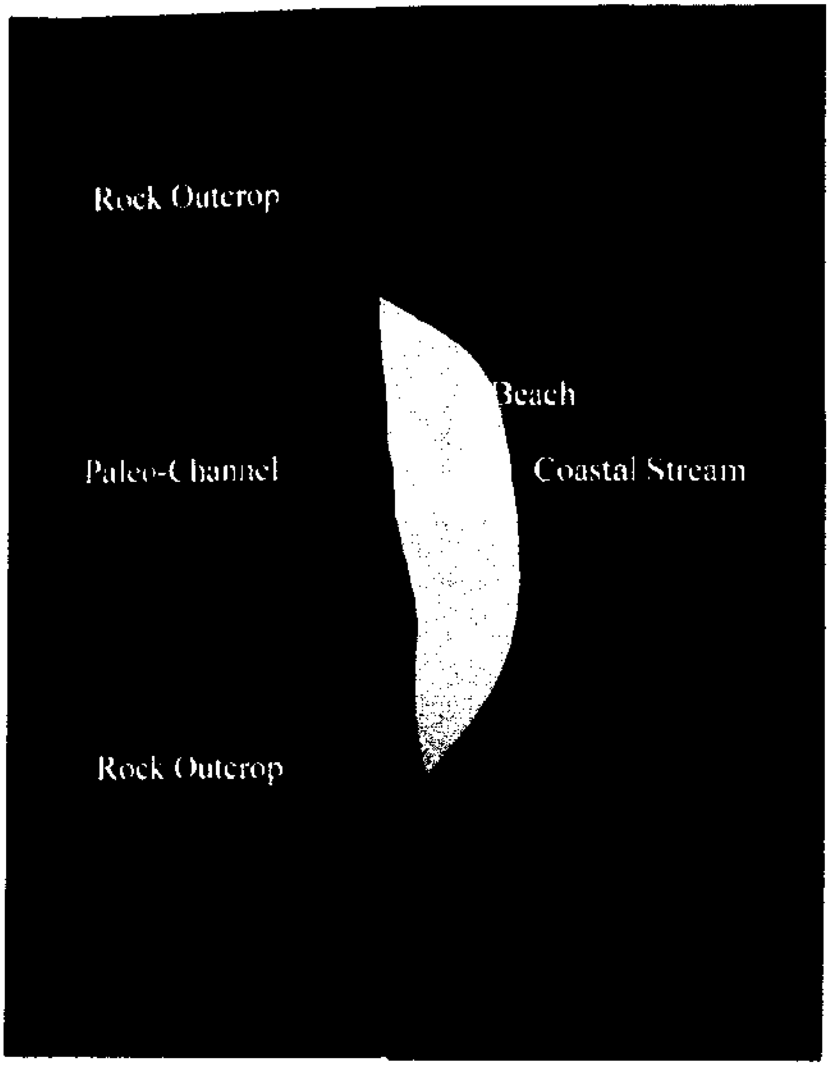

Figure 3. Pocket beach system showing headlands, coastal stream, and offshore rock outcrops

There is limited information about the pocket beaches found along the California coast. Much of the existing literature comes from studies in Australia or the Mediterranean where pocket beaches are also prevalent. Research from these areas is not always relevant to field observations at pocket beaches along the California coast. For example, the source of sediment for pocket beaches along the Mediterranean is mainly from rocky headlands bounding each beach. Sand is thought to remain in these "sediment tight" systems which have little input or output of sediment, (Pethick, 1984), other than from their confining headlands. This may not be true for all of California's pocket beaches. For example, in Santa Cruz and San Mateo Counties, the shale and mudstone cliffs that back the pocket beaches and form the headlands between them, are not a significant source of beach sand. The sediment supply for these central Californian pocket beaches is apparently derived from local stream input, littoral drift from upcoast, or onshore from the shelf. Thus, pocket beaches are not necessarily "sediment tight" and they probably have external sediment sources.

Differences Between Sandy and Rocky Coastlines

There is a dramatic visual distinction between a straight, open coastline having continuous wide sandy beaches with a ribbon of sand in the nearshore (Fig. 4a) and that of an irregular, rocky coastline with many barriers to sediment transport and dotted with small pockets

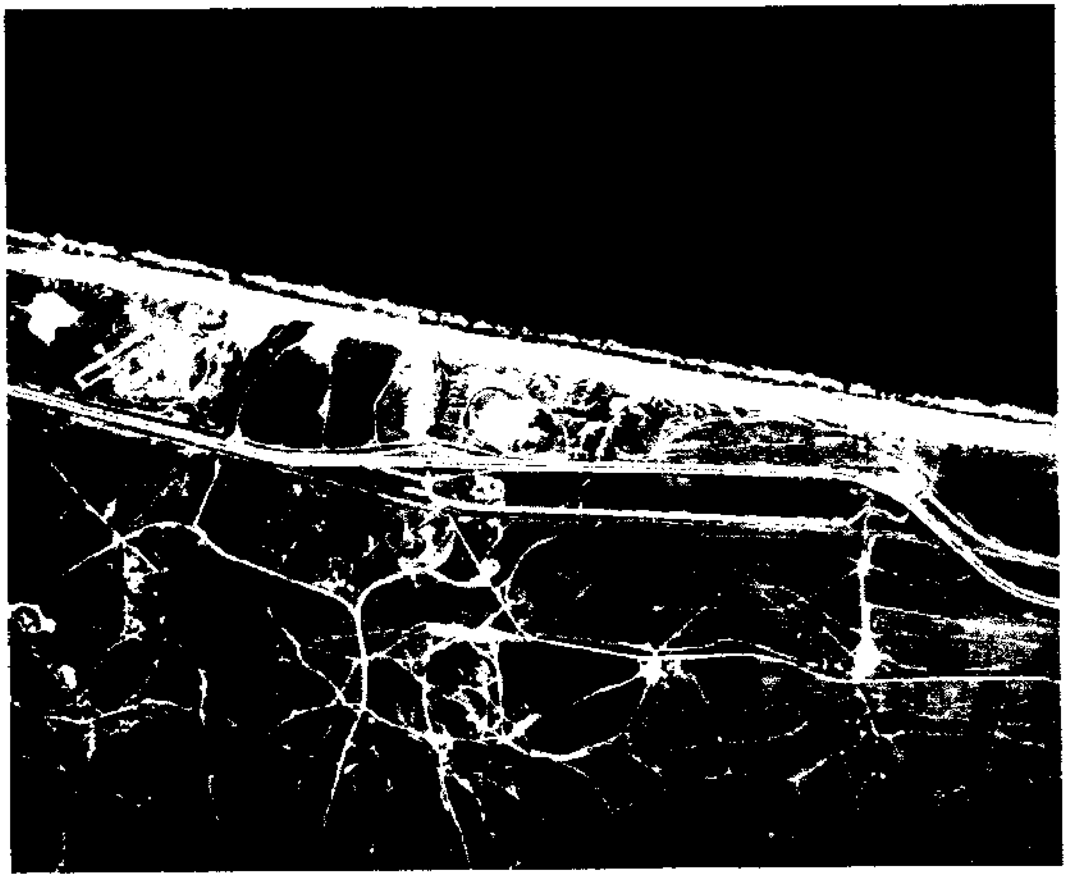

Fig. 4a. Vertical aerial photograph showing continuous coastline with wide sandy beach and ribbon of sand in San Diego county.

of sand (Fig. 4b). The processes of sediment transport along a continuous coastline including the interactions between the predominant wave direction, the longshore currents, the ribbon of sand and the beach itself, are well studied. Along a pocket beach coastline, however, where there is no apparent ribbon of sand, no continuous sandy beach, and where there are many protrusions and headlands which serve as barriers to movement of sand, the processes of longshore sediment transport are poorly understood.

Figure 4b. Vertical aerial photograph showing rocky, irregular pocket beach coastline in Santa Cruz county

Nearshore sidescan-sonar and seismic reflection mapping work by USGS/UCSC along the Santa Cruz county coastline, indicates that the offshore environment in this area is mostly rock outcrop. These rock outcrops are dissected with occasional shore normal or shore oblique, sediment-filled paleo-channels corresponding to onshore pocket beaches, (Anima and Tait, 1994; Tait, 1995; Anima *et al.*, 1996). The topographic relief between the surface of the sediment in the channel and the surface of the rock outcrop is as much as 2.5 meters. There is a distinct lack of sediment on the outcrops and there are large quantities of sediment in the offshore channels (Anima *et al.*, 1994).

Sediment Transport Processes on a Pocket Beach Coastline

Little is known about how sediment is transported on pocket beach coastlines. Even the most basic questions have not been answered. For example: what are the processes which transport sediment to pocket beaches and alongshore on a pocket beach coastline? How long does sediment remain on a pocket beach? How much does pocket beach sediment interact with sediment in littoral transport? To address these fundamental questions, four pathways of sediment transport along pocket beach coastlines and within pocket beach systems are important to evaluate: 1) sediment movement around headlands; 2) sediment transport over rock outcrops; 3) onshore/offshore movement of sediment; and 4) sediment movement within an isolated pocket beach system. A combination of these processes are likely to occur in pocket beach systems and along pocket beach coastlines.

Sediment movement around headlands: Rock headlands that separate pocket beaches are substantial barriers to sediment transport. Analysis of aerial photographs and limited field observations suggest that nearshore sediment is not moving in suspension or on the bed around the headlands between pocket beaches. It is possible that sediment is transported around headlands by large waves and strong currents during major storm events. Under normal conditions, however, it would be difficult to transport sediment from one pocket beach to the next close to shore around these headlands because they protrude beyond the breaker zone.

Sediment transport over rock outcrops: Due to the large relief (about 2.5 m) between channel sediment and rock outcrop, sediment transport over rock outcrops requires high energy conditions. Sediment must be suspended high enough into the water column so that it can settle out onto rock outcrops and be swept into the next offshore channel. Since high energy conditions are a prerequisite for saltation transport, it would follow that this type of sediment transport is episodic, occurring only during storm events along high-energy coastlines.

Onshore/offshore movement of sediment: Onshore and offshore sediment transport could occur both during storm events and normal seasonal conditions. We have observed strong seasonal changes both in the nearshore and subaerial pocket beach morphology indicating that sand does in fact move off the subaerial beach to form nearshore bars. If sediment moves far enough offshore, to the offshore sand sheet beyond the rock outcrops, and downcoast, it is possible that it may enter another paleo-channel. Sediment in a paleo-channel could move onshore and onto another pocket beach in the next season. This scenario suggests a plausible mechanism for longshore sediment transport.

Sediment movement within an isolated pocket beach: Another possibility is that pocket beaches are isolated systems with little input or output of sediment. Sediment may move back and forth on a pocket beach or into the nearshore as seasonal bars, but may not move far enough offshore beyond the rock outcrops to reach the offshore sand sheet. If the same sediment remains on one pocket beach without external sediment inputs, then a fining of sediment, as it gets reworked by waves, or a coarsening of sediment, as the finer material moves offshore in suspension, could occur over time.

In order to understand the importance of sediment transport pathways within a pocket beach system, we have initiated a study of two adjoining pocket beaches at the mouth of

Yellow Bank Creek, a coastal stream on the Central California coast.

Yellow Bank Beach Study
Seven miles north of the city of Santa Cruz at the mouth of Yellow Bank Creek (Fig. 5), two adjoining pocket beaches and their offshore channel are being extensively studied in

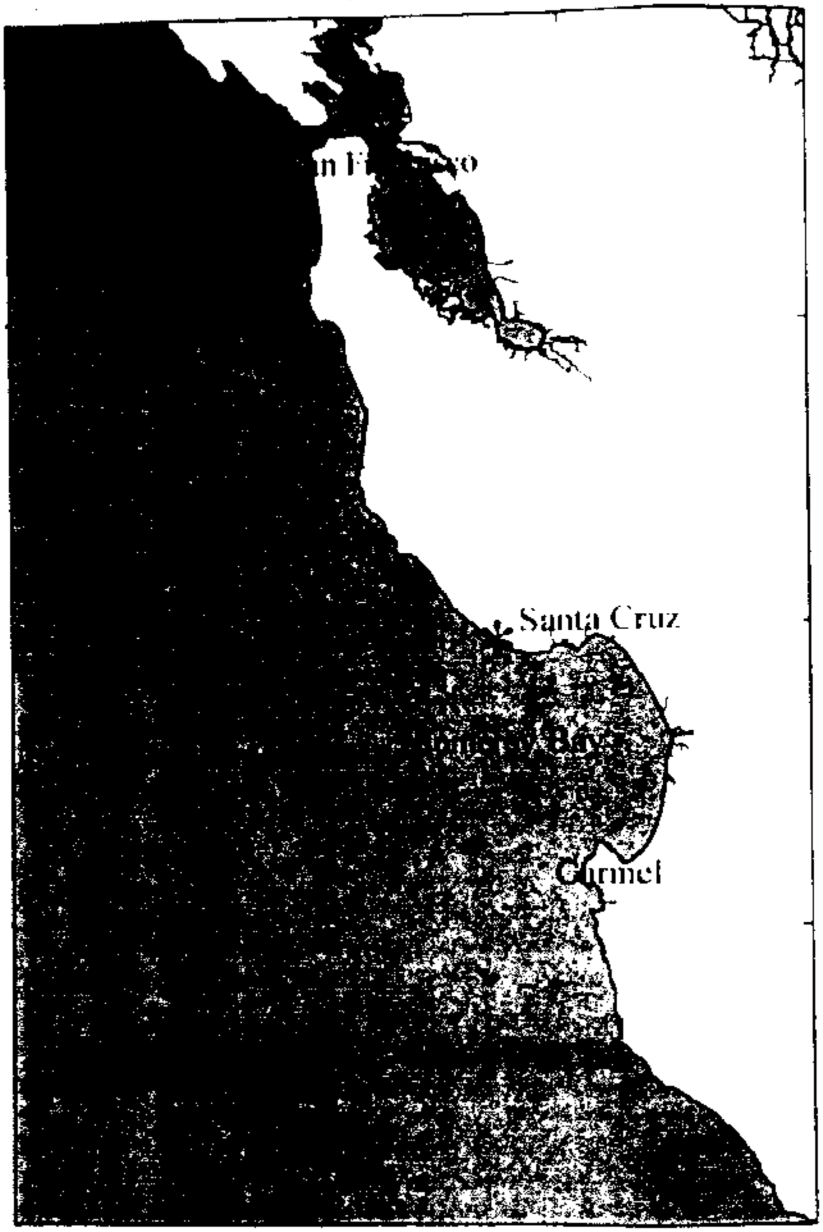

Figure 5. Geographical location map of Yellow Bank pocket beach study.

a collaborative project between the University of California, Santa Cruz Coastal Geology Laboratory and the U.S. Geological Survey's Coastal and Marine Group.

The onshore portion of this study involves biweekly beach profiling of three shore-normal profile lines extending into the nearshore on each of the two adjoining pocket beaches (Fig. 6). Wet-dry line surveys are also conducted to monitor changes in the extent of inundation by high tides and to determine if the base of the cliffs are being impacted by waves. For the offshore portion of this study, an instrument package has

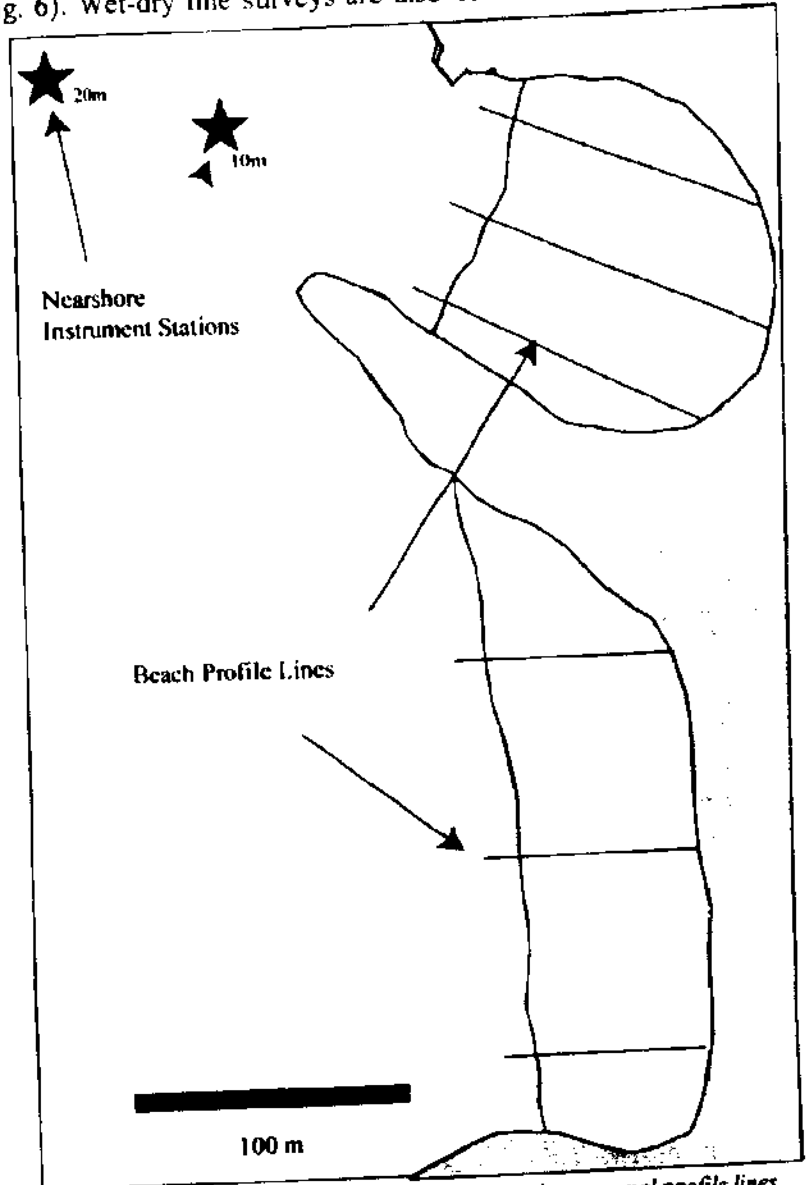

Figure 6. Site map showing the locations of six shore normal profile lines and offshore instrument packages.

been deployed in the paleo-channel about one kilometer offshore of the pocket beach in 10 meters of water. A second package will also be deployed in 20 meters water depth. These instrument packages include pressure sensors to measure wave heights, optical back scatter sensors to determine the amount of sediment in suspension, sonar altimeters to monitor changes in the height of the bed, current meters, and instruments to determine water salinity and temperature.

Data Collection

The combination of beach surveys and seafloor instrumentation data collected will document: 1) changes in beach and nearshore morphology from which changes in the volumes of sediment on the pocket beach can be calculated; 2) the characteristics of nearshore sediment transport in suspension, on the bed, or both; 3) wave and current characteristics; and 4) temperature and salinity conditions. Wave heights and currents have never before been documented at these depths in this rocky, high energy nearshore environment. These parameters are crucial for determining how and where sediment is transported. The main focus of this project is to monitor the morphological changes on the subaerial beach and nearshore, concurrently with changes in bed height and suspended sediment at 10 and 20 meters water depth. Having both onshore and offshore data will contribute to our understanding of how, at what rates, and under what wave and current conditions sediment transport takes place in a pocket beach system.

In addition to this project, 3 other pocket beaches within 15 miles of Yellow Bank Creek are being regularly profiled as part of a USGS study addressing the coastal impacts of the 1997/98 El Niño winter. By comparing the seasonal behavior of these four beaches, we can determine whether the changes occurring at Yellow Bank are consistent with changes on other pocket beaches and, therefore, if Yellow Bank beach is representative of other pocket beaches in this coastal environment.

SUMMARY

Pocket beach coasts are found in every coastal county in California; they comprise 28 % of the coastline and are an important state resource. Pocket beaches in California have not been well studied and as a result are poorly understood. The Yellow Bank pocket beach study will provide extensive information about pocket beach sediment transport processes which may be applicable to other pocket beach systems in California or on other coasts.

Sediment transport pathways are important to identify since coastal management and protection measures can interfere with natural coastal processes. By understanding the natural dynamics of coastal systems, we can make more sound and sustainable coastal engineering and management choices. Understanding the dynamics of pocket beach systems is important for beach nourishment projects. Timing of nourishment, both seasonally and with respect to the tidal cycle, as well as the positioning of the material on the beach is important to the success of the nourishment project. Since there are major differences between wide sandy beaches on open coasts and pocket beaches on rocky coasts, effective coastal management must include and account for varying beach environments and their distinctive processes. This understanding is crucial if we are to preserve beaches, one of California's most valuable resources.

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COASTAL PROCESSES WITHIN A SMALL POCKET BEACH
CRESCENT BAY, LAGUNA BEACH, CALIFORNIA

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INTRODUCTION

The Coast of California Storm and Tidal Waves Study (CCSTWS), Orange County, is a study sponsored by the U.S. Army Corps of Engineers, Los Angeles District, the County of Orange, and several municipalities that is intended to quantify coastal processes along the coast of Orange County. One element of the CCSTWS-Orange County work involved a comprehensive study of Crescent Bay, a small pocket beach located in the city of Laguna Beach, California. The location of Crescent Bay within the Laguna Beach Group of Mini Littoral Cells is shown in Figure 1.

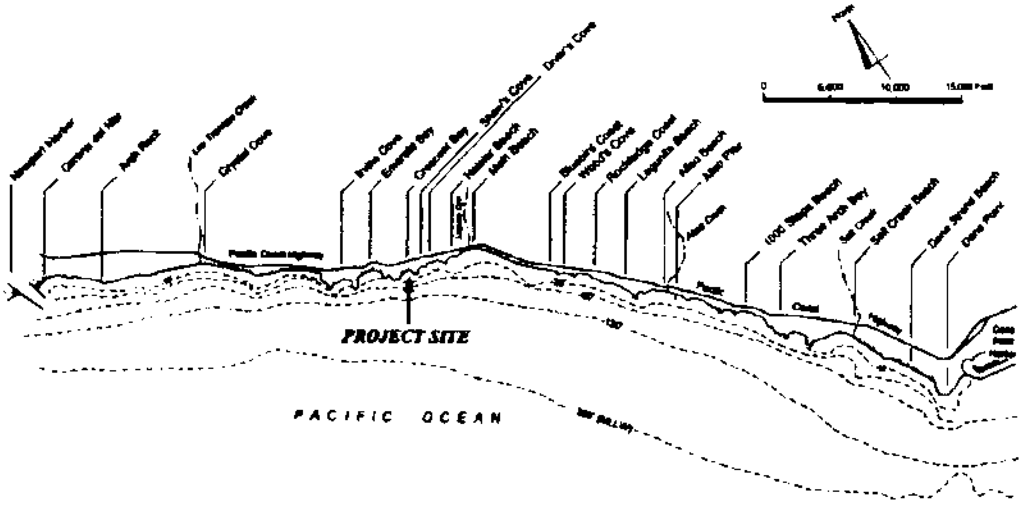


FIGURE 1
CRESCENT BAY LOCATION MAP

Crescent Bay spans about 900 feet in alongshore dimension and is defined by two rocky headlands on the east and west sides. The headland length from the back beach line to the location at which the headlands enter the offshore seabed is about 800 feet, therefore the small cove can be considered to be a three-sided box, with the side dimensions being 800 to 900 feet. No significant fluvial sources of sediment enter the bay.

The study of Crescent Bay was begun in early June 1994. The project goals were to determine:

- The sediment dynamics within the bay;
- The nature of the onshore-offshore-alongshore sand transport, both within the cove and along the adjacent coast;
- The importance of the bluff contribution to the sediment budget;
- Seasonal changes in the beach and nearshore conditions;
- The extent of long-term beach stability.

The components of the Crescent Bay study included the following:

- Fluorescent Sand Tracer Study
- Stake Field Study
- Comparative Beach and Bathymetric Profiling
- Sub Bottom Profiling of the Nearshore Zone
- Water Jet Probing to Determine Sediment Veneer Thickness
- Historical Aerial Photo Analysis

The period of field study spanned June 1994 to May 1995, with field trips performed in June, July, and October 1994, and May 1995.

SAND TRACER STUDY

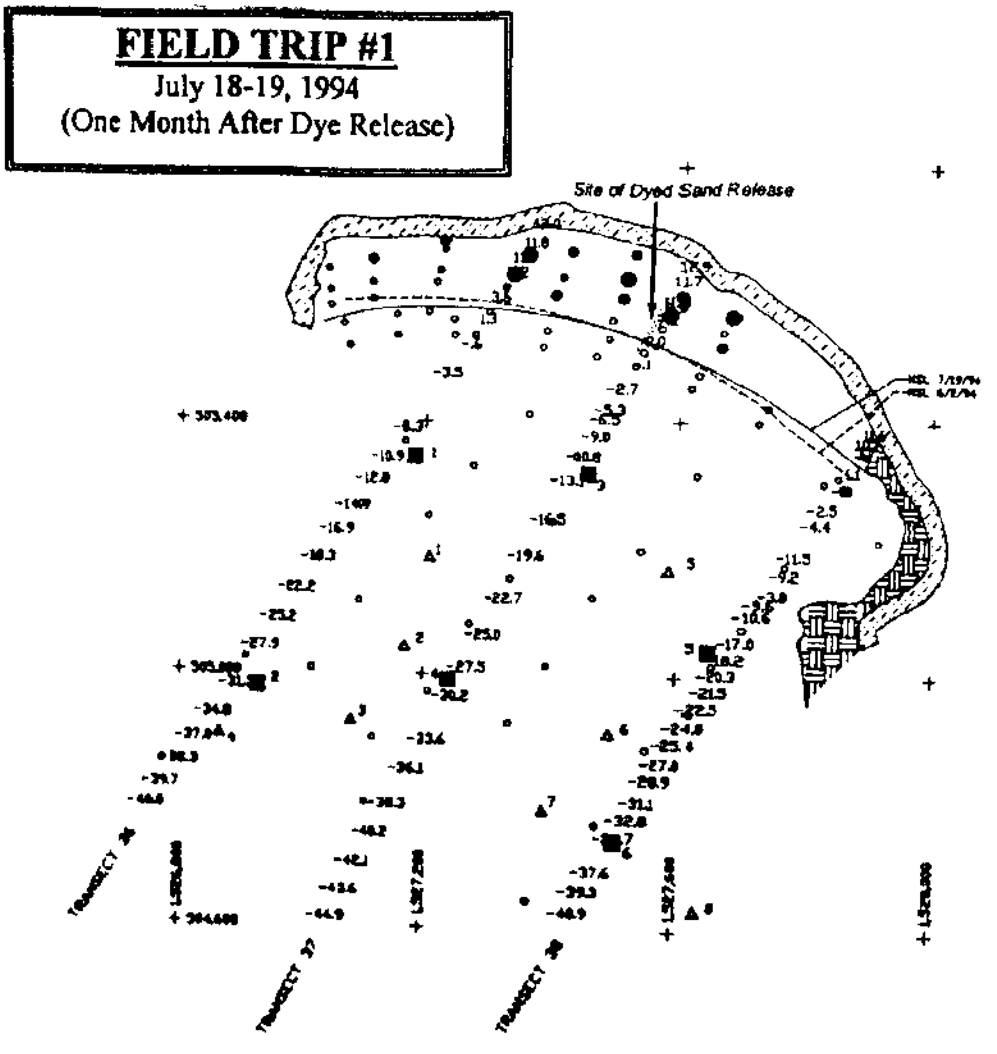
To provide a better understanding of the sediment dynamics within Crescent Bay a tracer study employing sand coated with red fluorescent dye was performed. While seasonal sand level fluctuations along the pocket beaches of this area are noted, the extent to which sand moves along the coast from cove to cove (or to/from the offshore) is unknown. From a long-term planning perspective, bluff erosion control structures have been considered for use at Crescent Bay. By stopping bluff erosion through the construction of seawalls and other coastal protective works, the natural sand source for these confined beaches would be eliminated. Should offshore losses of beach sand occur and the natural sand source from the uplands be halted, future beach stability would rely on natural sand replenishment from the offshore, from the adjacent beachs around the headlands, or from human-derived beach nourishment operations.

On 24 June 1994, a total of 625 pounds of dyed tracer sand was placed on the beach at Crescent Bay. The sand was native beach material that was collected at the site of release and dyed at an offsite location. The non-toxic red epoxy dye used to color the tracer sand was readily identifiable in a sand sample when viewed in the dark with the aid of a black light. The time of tracer sand release coincided with a tidal elevation of -1.5 feet (MLLW). The sand was distributed in a shore-perpendicular stripe having a length of 87 feet, that spanned the +1.5 ft and +8.7 ft (MLLW) elevations. The sand was placed at the center of Crescent Bay. Release of the tracer sand in this fashion allowed distribution by waves and currents to occur within a brief time frame. The material was completely dispersed within six hours of release.

FIELD TRIP #1

The first field trip to search for the dyed sand was performed on 18-19 July 1994—24 days following the initial tracer injection. A map of the sediment collection sites is presented in Figure 2. Each sand sample was collected by inserting a 2-inch diameter, 6-

FIGURE 2



FIELD TRIP #1
July 18-19, 1994
(One Month After Dye Release)

inch long plastic tube into the beach or seabed. Each sample was extruded from the collection tube and placed into a plastic bag, marked, and sealed. The location of each sample was precisely surveyed using an electronic distance measurement device.

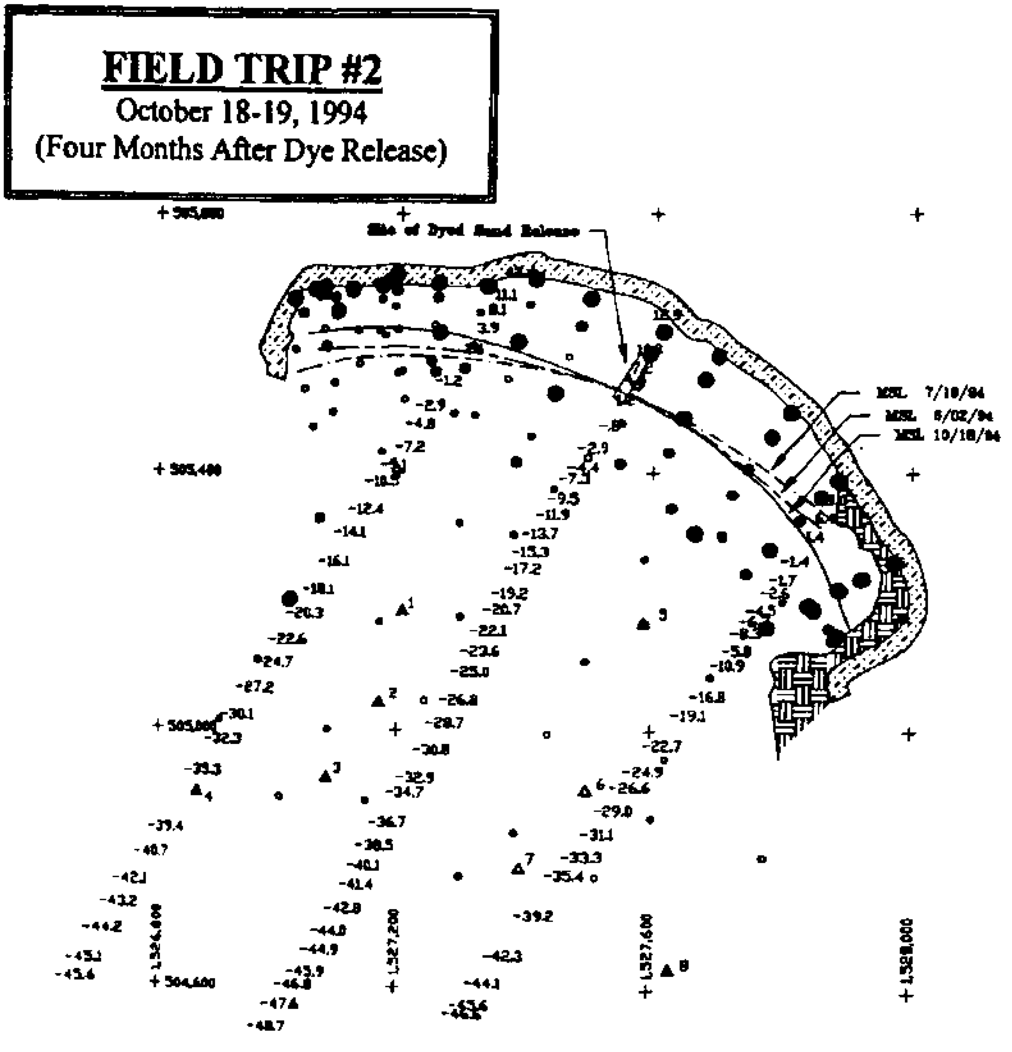
Prior to sand analysis, the samples were thoroughly dried. Each sample was then spread onto a flat plate. In a dark analysis area, illuminated only by a fluorescence-sensing "black" light, each sample was examined to determine the presence of the dyed sand tracer. The results of this effort are displayed in Figure 2. Small open circles are sites of sediment sampling where no dyed sand was detected. Filled circles indicate sites where dyed sand was found, with increasing circle size representing greater dyed sand concentration.

The results obtained during the field trip of 18-19 July 1994 indicate the dispersion of sand throughout the upper beach at Crescent Bay. Dyed sand was found along the entire beach area defined within the west and east headlands. Small quantities of dyed sand were detected in several surfzone samples, however, no dyed sediment was found at any offshore sampling sites. During the tracer deployment period, comparative bathymetric results indicated a movement of sand from the east to the west within the bay, as noted by the counter-clockwise rotation of the position of the Mean Sea Level (MSL) shorelines between June and July shown in Figure 2. The beach sand elevation at the west end of the beach increased about 2-3 feet during the period since tracer release. Concurrently, sand loss was noted both visually and through survey results from the east side of Crescent Bay. Offshore sand movement appeared to be slight, based on minor changes in bathymetry at the deeper (-25' MLLW or greater) stake field locations. Therefore, we believe that the majority of the dyed sand was moved onshore by the summer surf and swell conditions. Offshore distribution of beach sand apparently had yet to occur, based on both the tracer sand experiment and the bathymetric survey/stake field observations.

FIELD TRIP #2

The second sediment tracer collection field trip was conducted on 18-19 October 1994. In addition, sand samples were collected at sandy beaches located both east and west from Crescent Bay. In contrast to the findings of the first tracer recovery field trip of July, the October effort clearly indicated that sand had moved from the beach to the offshore zone. The results of this field investigation are shown in Figure 3. The sand tracer findings, along with the results of the survey operations, clearly indicate that significant sand movement had occurred during the July-October time period. The MSL shoreline experienced a significant clockwise movement during this period. The west side of the bay experienced erosion, while accretion of the beach was noted on the east side of the bay. No dyed sand was found in the sediment collected at the pocket beaches located immediately east and west of Crescent Bay.

FIGURE 3

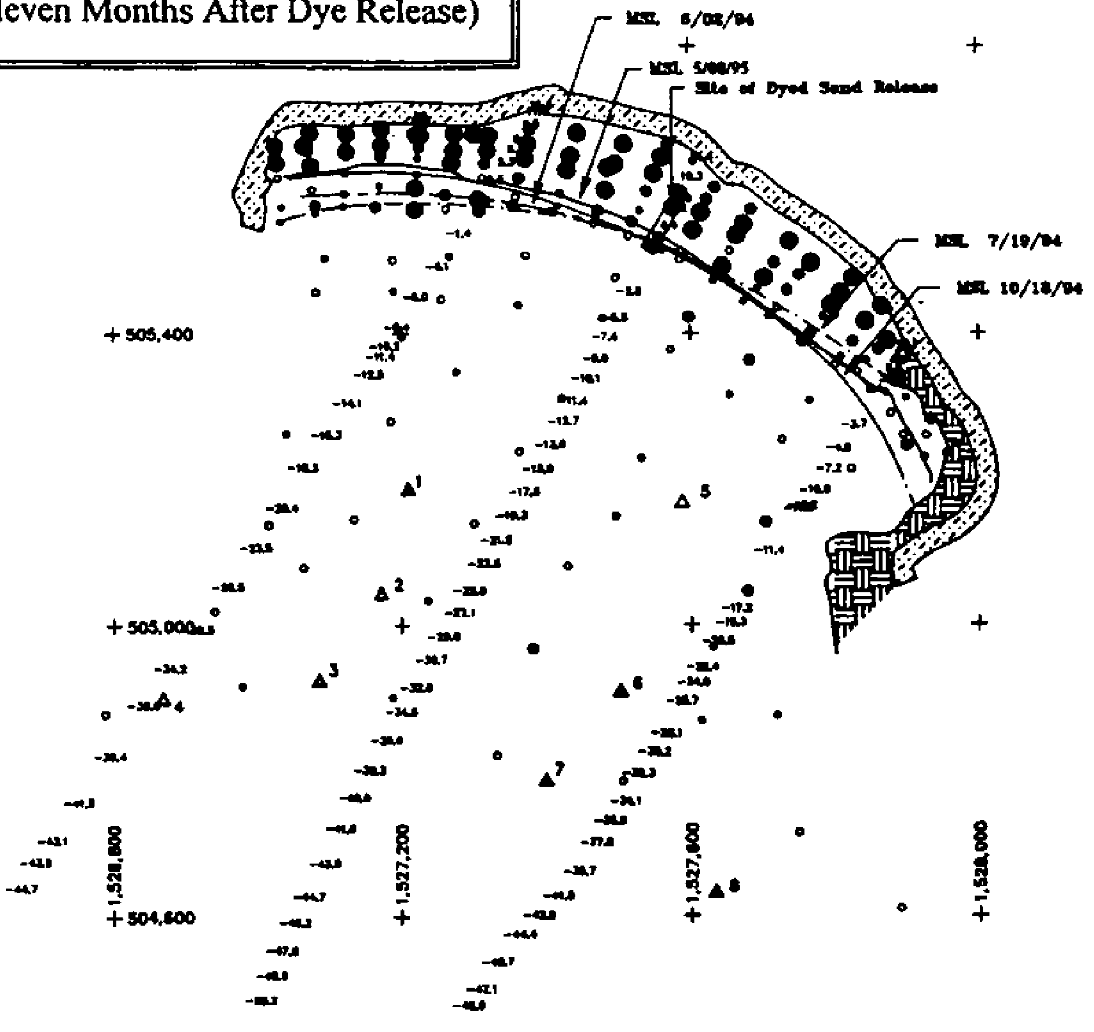


FIELD TRIP #3

The third sand tracer collection field trip was performed on 7-8 May 1995, following a stormy winter season during which large volumes of sand were removed from the beach at Crescent Bay. Based on visual observations in January 1995, it was clear that large volumes of sand were lost from the beach during the severe winter storm period. Much sand was stripped from the beach thereby exposing resistant bedrock and cobbles. By the time of the May 1995 field trip, sand had returned to the beach. However, recovery of the beach was not complete at the time of the May 1995 field trip. At all locations within the bay, the MSL shoreline retreated relative to the October 1994 position. During the May field trip, a wide-ranging sand sample collection effort was undertaken to determine the presence of dyed sand within Crescent Bay, and within the adjacent coves to the east (Shaw's Cove) and to the west (Emerald Bay). Figure 4 is presented to show

FIGURE 4

FIELD TRIP #3
May 7-8, 1995
(Eleven Months After Dye Release)



the locations of the sampled sand and the concentrations of the dyed sand within the samples. Dyed sand was not found in the samples collected at Shaw's Cove (located to the east of Crescent Bay). One sample was found to contain dyed sand at Emerald Bay (located to the west of Crescent Bay). It is apparent that the sand that returned to the beach following storm erosion in January was composed of sand that had previously been located in Crescent Bay, based on the wide spread presence of the tracer sand.

STAKE FIELD SURVEY

A stake field was implanted in the offshore waters of Crescent Bay in June 1994, to determine the extent of sand level fluctuations within the Bay. The stakes were eight-foot long galvanized steel pipe (1-inch outside diameter) that were jetted into the substrate to about six feet of their length. A total of eight steel stakes were implanted, four each along both the east and west sides of the bay. The water depths at which the stakes were placed were selected based on the intended need to determine sediment movement in and around the north and south headlands of Crescent Bay. During each of the data collection field trips, measurement of the height from the top of each stake to the sand surface was made. Generally, the sand level fluctuations were modest, within the 0 to 0.2 ft range. In shallow waters (15-20 ft water depths), several of the stakes were dislodged and found lying flat on the seafloor. The cause of this movement is believed to be a combination of wave-induced scour and oscillatory wave forces acting on the pipe.

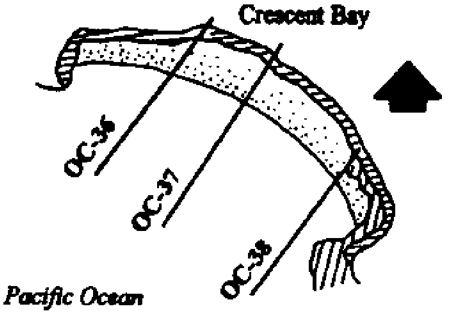
In several cases, while none of the offshore stakes indicated significant seabed elevation changes, the exposed surface of each stake was covered with soft algae which served as an indicator of sand motion past the stake. At one stake located in a water depth of about 30 feet, the lower 0.4 feet of the stake was bare, while the upper portion of the stake was covered in algae. Despite the fact that the seabed elevation was lowered by 0.2 feet relative to the previous survey, the pattern of algae growth indicated more significant seabed elevation changes (and sediment transport) at this location.

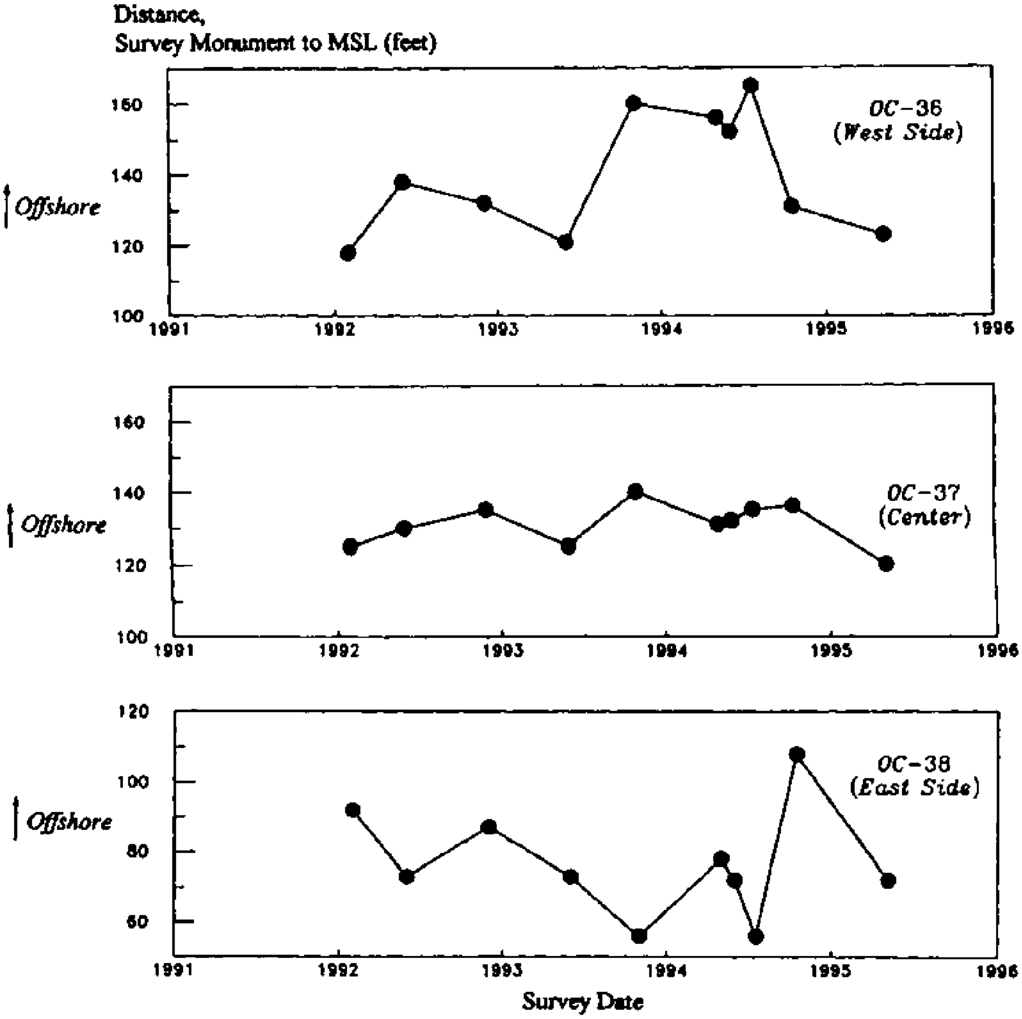
The greatest changes in the height of the seabed below the fixed stakes occurred between the October 1994 and May 1995 surveys. Seabed elevation changes noted during this period ranged from 0.2 to 0.8 feet. Seabed accretion was noted within the central portion of Crescent Bay, in water depths within the -19 to -35 foot (MLLW) range. Seabed erosion occurred at sites located off the west and east headlands, respectively, in water depths of about -35 feet (MLLW). The 0.8 ft seabed elevation change occurred at a water depth of -35 ft (MLLW), suggesting active sediment transport at that depth.

SHORELINE AND BEACH VOLUME ANALYSIS

Review of the comparative Mean Sea Level (MSL) positions noted seasonal rotation of the shoreline in response to incoming wave energy. The center of the beach acts as a nodal point, where small changes in the MSL shoreline are noted relative to the more dramatic fluctuations that occur at the east and west sides of the cove. Consideration of all the survey data spanning the 1992-1995 period illustrates this fact in Figure 5.

FIGURE 5
SHORELINE FLUCTUATIONS
CRESCENT BAY





At each of the three survey profiles within Crescent Bay (OC-36, OC-37, and OC-38), the distance from the fixed survey monuments to the Mean Sea Level position was determined. As is evident, significant fluctuations exist in the MSL position on the west and east sides of Crescent Bay (at Transects OC-36 and OC-38, respectively). This information indicates an opposing shift in shoreline position within Crescent Bay in that shoreline recession on one side of the bay is typically associated with shoreline advance on the opposite side. During these shifts in shoreline position on either side of Crescent Bay, the central portion of the beach experienced no significant change. This seasonal shoreline migration has been previously noted in historical aerial photos of Crescent Bay and other pocket beaches within Laguna Beach (U.S. Army Corps of Engineers, Los Angeles District, 1995). During energetic winter periods noted in 1992-93 and 1994-95, all three profiles within Crescent Bay experienced shoreline recession.

The beach fluctuations at Crescent Bay are also indicated by beach volume comparisons. Figure 6 presents the volume of beach material per lineal foot of beach

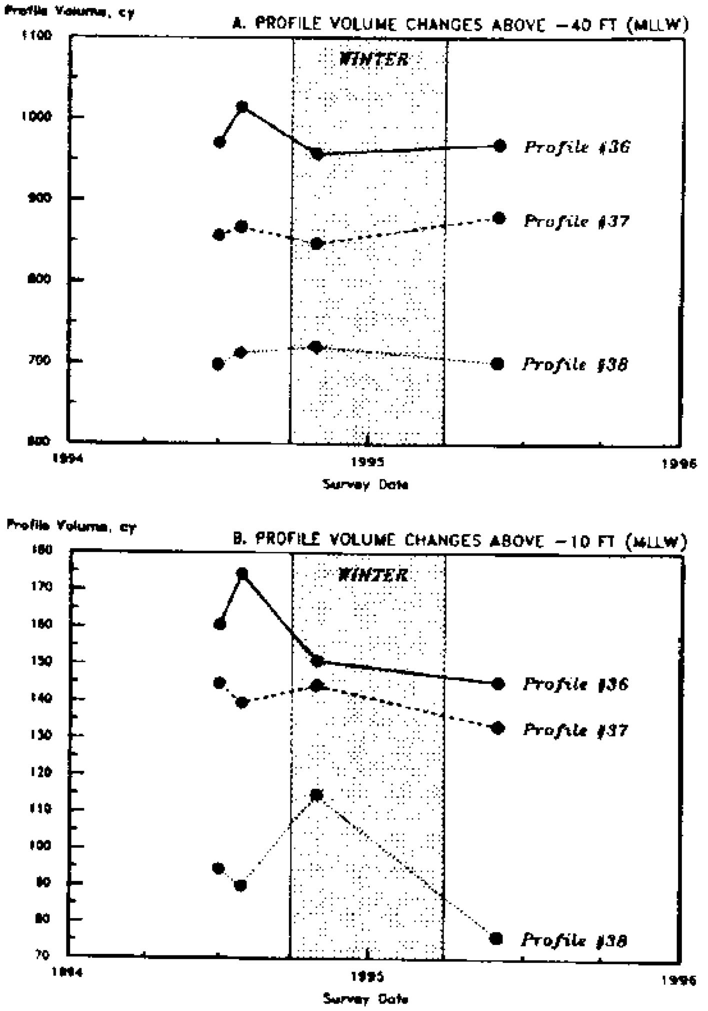


FIGURE 6: FLUCTUATION OF PROFILE VOLUME WITHIN CRESCENT BAY

width contained in the three CCSTWS beach profiles (OC-36, OC-37 and OC-38) for the four surveys conducted in June, July, and October 1994, and May 1995. The volumes have been determined for two elevations categories: a) the entire profile lying above -40 feet (MLLW), and b) the volume in the beach and nearshore zone lying above -10 feet (MLLW). As indicated, the nearshore volumes above the -10 foot isobath experience greater change, with total volume fluctuations of 20 to 50% at the east and west profiles. Again, the east and west sides of the cove experience opposite movement trends (a volume increase in the west profile is associated with a volume loss at the east profile, and vice versa) except for during the winter period when volume loss is noted at all three profiles. Conversely, the total volume contained in the profile above the -40 foot isobath was relatively constant during the 12 month survey period. This indicates that the cove volume to this depth remains fixed, and perhaps cannot be overfilled given critical balances between beach slope, grain size, and wave energy. Particularly if one focuses on the first and last data points for each profile (representing the June 1994 and May 1995 data) the volume within each profile to the –40 foot water depth is essentially constant.

CONCLUSIONS

Based on the information gained from the Crescent Bay field study spanning June 1994 -May 1995, the following general conclusions can be presented:

- The dyed tracer sand that was placed on the beach on 24 June 1994 was widely dispersed throughout the beach and nearshore zone of Crescent Bay to water depths of -35 to -40 ft (MLLW). Following beach sand loss caused by major storms of January 1995, the beach sand that returned to the beach by May 1995 contained tracer sand. In May, tracer sand was noted in one sand sample collected at Emerald Bay (the adjacent cove to the west). No tracer sand was found at Shaw's Cove (the adjacent cove to the east). These findings lead to the conclusion that the sand within Crescent Bay remained in the bay with only slight exchange with offshore and/or alongcoast locations.
- During fairweather periods, the offshore stake field noted relatively small changes in the documented seabed elevations—on the order of 0.1 to 0.2 feet. During winter storm periods spanning October 1994 and May 1995, seabed changes of as much as 0.8 feet were noted in water depths of as much as –35 feet.
- Comparison of the survey data indicated an alternating eastward and westward movement of beach sand within Crescent Bay. This seasonal shift in sand is evident at other pocket beaches of Laguna Beach, based on air photo data and observation by long-time beach residents.

Comparison of aerial photos dating back to 1938 indicated sesasonal beach shoreline changes, however, there is no evidence of long-term beach erosion or accretion within Crescent Bay. This is the case at a number of other pocket beaches in Laguna as well. Based on the combined findings of this study, the Crescent Bay beach volume appears to be stable in the long term, despite significant seasonal fluctuation.

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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 raised 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.

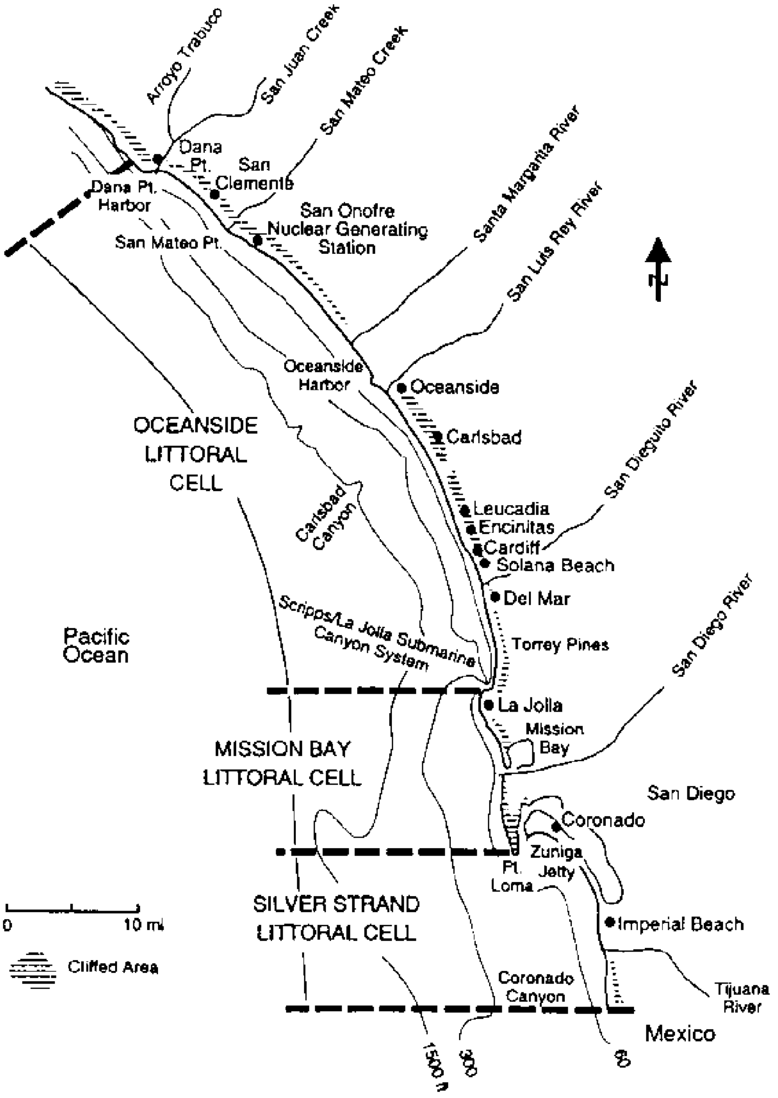


Figure 1 - San Diego County shoreline map (From Flick, 1994).

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 seacliff 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 seacliffs, providing optimal failure conditions. The majority of the rocks exposed in the San Diego County seacliffs are Eocene siltstones, 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 seacliffs from the Point Loma Peninsula to La Jolla (Kennedy, 1975). In general, the seacliffs 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 seacliff erosion. In addition, large volumes of sand-sized material are artificially supplied to the beaches via public and private beach nourishment projects. Everts (1991) has determined that the sediment supplied to San Diego County beaches may serve as an effective buffer against wave induced seacliff 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

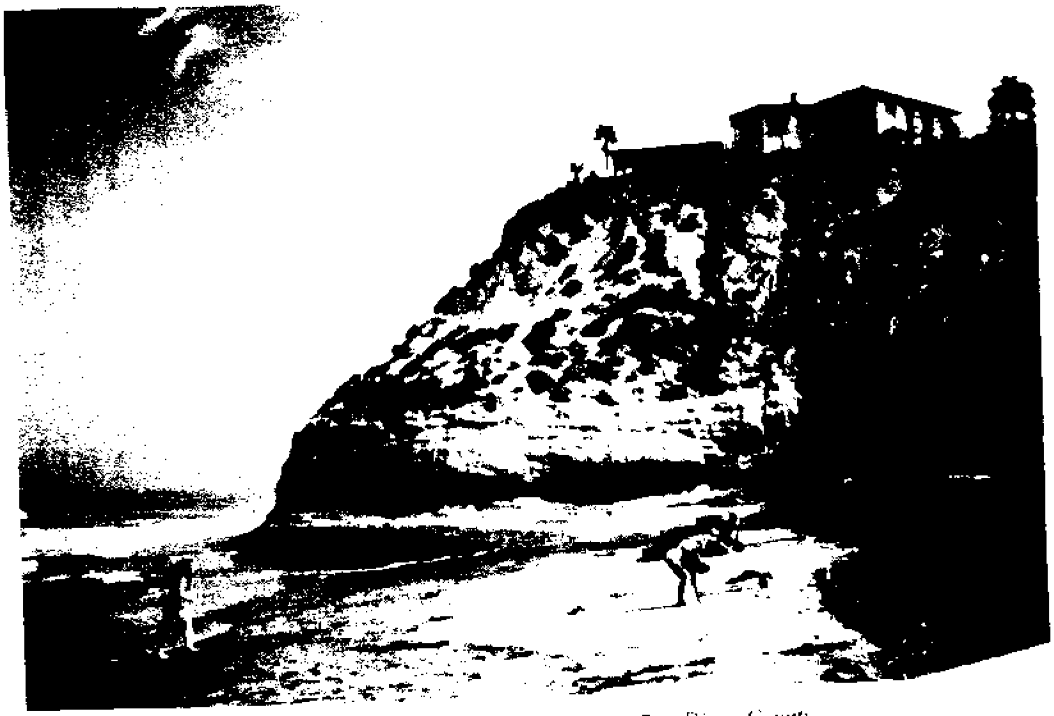


Figure 2. Typical cliff-top, Solana Beach, San Diego County.

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).

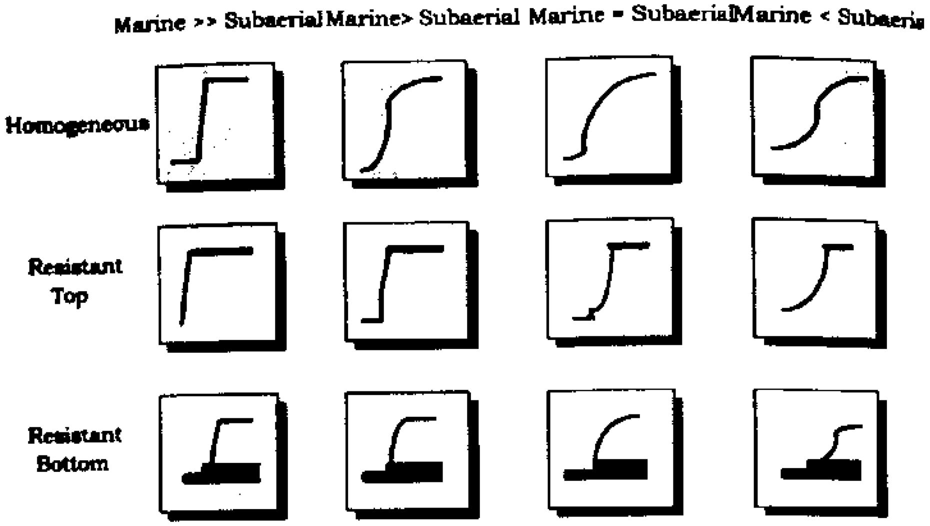


Figure 3 - Classification of coastal cliffs based on relative importance of marine vs. terrestrial erosion (adapted from Emery and Kuhn, 1982).

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 photography taken in 1932, 1949, 1952, and 1956 and at scales of 1:9600, 1:20,00, 1:12,000, and 1:12,000 respectively, provided historical shoreline data. Although the use of four sets of historical 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 (Inman 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 clifftop. 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 clifftop. 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 armoring 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.

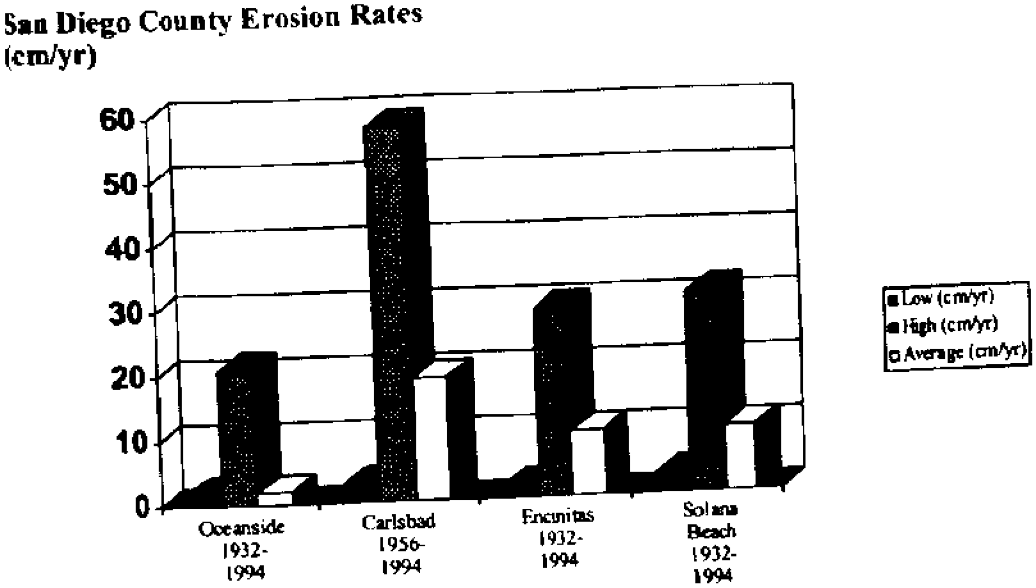


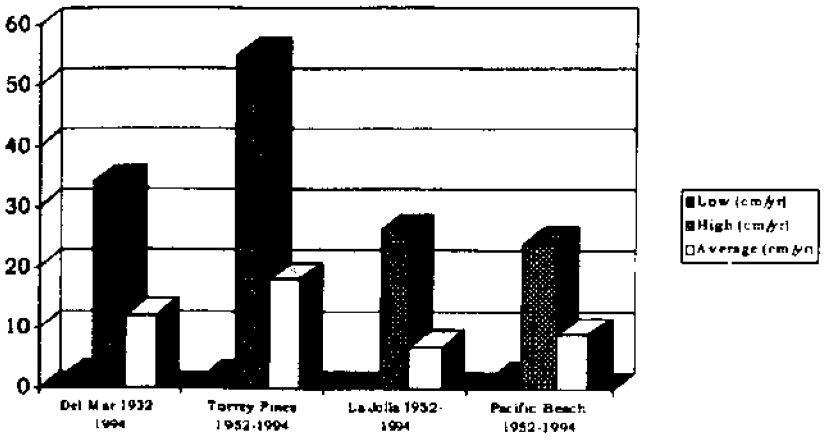
Figure 4. San Diego County FEMA Erosion Hazards Project erosion rates.

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 Pliocene 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 dis-continuous 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)

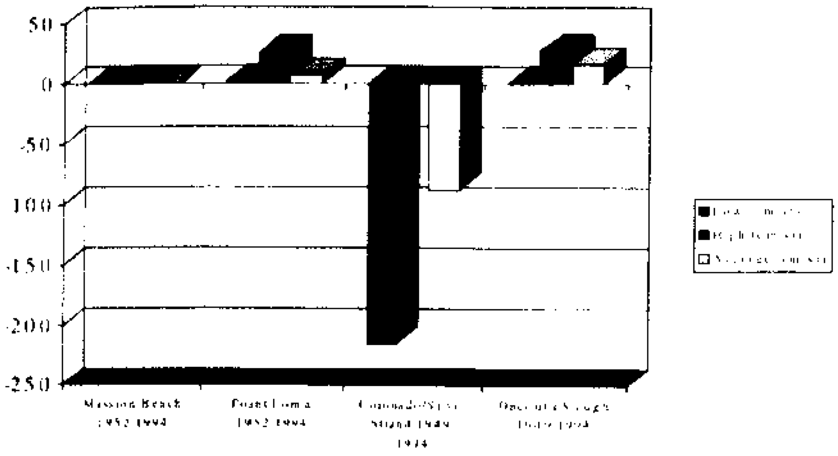


Figure 6. San Diego County FEMA Erosion Hazards Project erosion rates.

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 (Selby, 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.

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GEOTECHNICAL CONSIDERATIONS FOR THE BATIQUITOS LAGOON ENHANCEMENT PROJECT

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ABSTRACT

The Batiquitos Lagoon Enhancement Project is environmental restoration by the Port of Los Angeles (POLA) to obtain mitigation credits for new major reclamations in deep water marine habitat areas in the Outer Los Angeles Harbor. The project consists mainly of tidal and subtidal restoration of approximately 595-acres of coastal wetland located in Carlsbad, California. The project's primary goals were to improve water quality, wildlife habitat, and to provide beach nourishment shoreline protection. The three most significant of these considerations included lagoon sediment characterization, subaqueous disposal of fine-grained sediment, and retrofitting of a railroad trestle.

INTRODUCTION

Batiquitos Lagoon is the largest coastal lagoon in southern California and is about 2.5 miles long and 0.5 miles wide (Figure 1). Batiquitos Lagoon consists of three

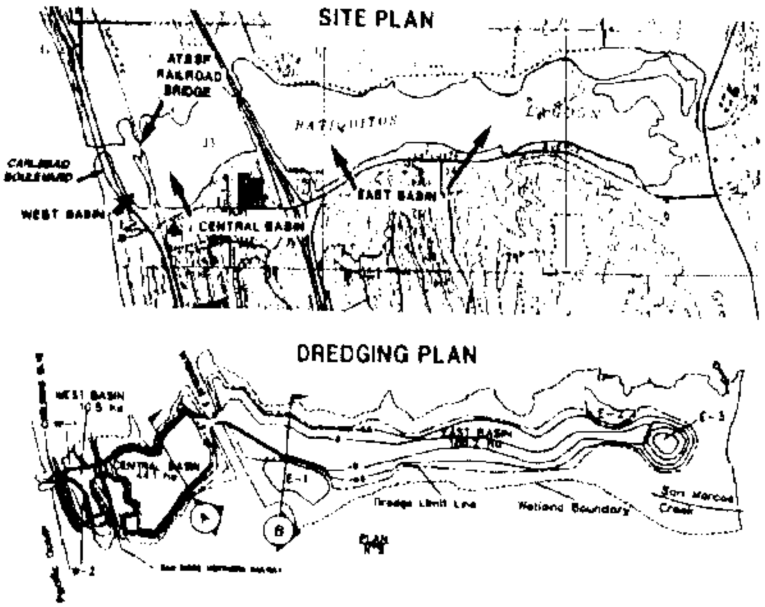

Figure 1 Batiquitos Lagoon Site Plan and Dredging Plan

interconnected basins (West [WB], Central [CB], and East Basins [EB]) delineated by four north-south trending transportation corridors. These include California Highway 101, the San Diego Northern Railroad, Interstate I-5, and El Camino Real. Historically, these corridors had restricted tidal prism flushing and upland developments had increased sediment yield to the point of threatening the lagoon's sensitive wetland environment (Sales and Appy, 1994). The primary objectives of the project were to improve water quality by increasing the tidal prism and providing a stable inlet; to improve wildlife habitats by creating protected endangered species nesting areas; and to improve shoreline protection by constructing wide sandy beaches. Final approval of the design required meeting environmental objectives and included numerous technical challenges.

Environmental project features of the project included 38 acres of nesting habitat, 98 acres of low marsh, 144 acres of intertidal water habitat, 148 acres of subtidal water habitat, and 1.6 mcy of beach nourishment. Engineering project features included two 300-foot long tidal inlet jetties, 3,000 feet of rock revetment shore protection, 37,000 square feet of articulated block mat erosion control, 1.8 mcy of subaqueous fine-grained sediment disposal, replacement of two coastal highway bridges, seismic retrofitting of a railroad trestle, scour protection for five bridges, and relocation of utilities. Approximate dredge volumes included 2.3 mcy of CB sandy material used for beach nourishment fill and nesting habitat sites; 1 mcy of EB fine-grained material placed in the CB disposal pit; and 100,000 cy of WB sandy material used as capping material for the CB.

Construction activity restrictions with respect to staging, water quality, water level control, permitted dredging periods, pile driving noise, traffic detours, public beach access, and general operations increased the complexity of the project. Furthermore, performance requirements for the 1st and 10th years after project completion were established in order for the POLA to obtain desired mitigation credits.

Geotechnical Investigations

Geotechnical investigations included evaluation of offshore, beach, and lagoon surface and subsurface conditions using conventional borings, vibracores, CPT soundings, jet probing, beach profiling, and direct observations. Laboratory testing included standard geotechnical tests as well as large diameter column settlement tests on very soft bulked sediments. Non-destructive and geophysical testing were used to evaluate bridge pile foundations.

A layer of black organic laden clayey sediment less than 2 feet thick was present over the entire lagoon surface. Sediments below this layer indicated relatively clean sands to the west and fine-grained low to high plasticity silts and clays to the east. Lenses of rounded gravels and cobbles up to 4 inches in size were located in the West Basin and along the denuded shoreline. Offshore sediments consisted of medium to very fine clean sands. A high continuous gravel/cobble berm severed tidal flushing.

Beach Nourishment and Nesting Habitat Construction

CB dredge depths were to elevations of -20 to -25 feet NGVD over an area of about 60 acres for the purpose of obtaining sandy material for beach nourishment and nesting habitat construction. Electric powered hydraulic cutterhead suction dredges were used. Dredged sands were placed as fillet beaches adjacent to the new inlet jetties, as conventional longshore beach fill at Ponto Beach (2.5 miles to the north), and as new low elevation nesting habitats.

CB sediments in the upper 20 feet consisted of poorly graded medium to very fine sand with and without silt and shell fragments (d_{50} of 0.1 to 0.3 mm). The percent passing the Nos. 40, 100, and 200 sieves ranged from 80 to 100%, 15 to 80%, and 2 to 12%, respectively. Coarser sands were encountered below a depth of 20 feet (d_{50} of 0.2 to 0.5 mm). Sediment volume losses occurring during placement of the CB sands for beach nourishment and nesting habitats have been estimated to be about 20 to 40%. Lost sediments were mostly materials which could pass the No. 100 sieve. The total shore length of nourished beaches was about 6,000 feet. Beach widths at the end of construction generally ranged from 150 to 200 feet. The oxygen deficient (reduced) insitu sands placed on the beaches were light to dark gray in color at the time of dredging. These sands exhibited significant "sun bleaching" after placement.

Subaqueous Fine-Grained Sediment Disposal

The most significant geotechnical consideration of the project included subaquaeous disposal of about 1.8 mcy of fine-grained sediments from the EB to the overdredged CB. These materials were also evaluated for upland and offshore disposal. However, permit and cost restrictions eliminated these options. In addition, requirements imposed by regulatory agencies necessitated that the final CB subtidal bottom elevations be between -4.5 to -9 feet NGVD for a period of 10 years after construction.

Analyses for confined disposal of fine-grained sediments utilized large diameter column settling tests, estimation of bulking factors, flocculation and sedimentation rates in seawater, finite-strain consolidation parameters, management of seasonally placed of dredged sediment volumes, and long-term settlement modeling and monitoring. Hydrographic surveys over the 3 year construction period were used to calibrate and update settlement prediction models and adjust dredging phases.

East Basin Sediments

Insitu EB sediments were characterized by a tapering wedge of fine-grained sediments ranging from low and high plasticity silts and clays overlying silty to clayey sands. The sand content of the fine-grained soils range from 0 to 20% with an average of about 10%, had dry densities of about 45 to 70 pcf, and undrained shear strengths of 100 to 200 psf. The fine-grained content of the sandy soils were about 10 to 30% with an average of about 20% and had dry densities of about 70 to 105 pcf. Composited EB sediments to be dredged were estimated to be roughly 23% sand and 77% as fine-grained material.

Column Settling Tests

Ten large diameter column settling tests were performed to evaluate nonlinear time-dependent consolidation properties of the sediments. The tests were performed in accordance with the published procedures (USACE, 1987). The tests were performed using three 8-inch diameter by 8-foot tall clear acrylic columns fitted with sampling ports at 6 inch vertical intervals. Sediment slurries were mixed using filtered seawater. Initial bulked slurry concentrations ranged from 113 to 172 g/l which is in the range of concentrations typically observed in hydraulic cutterhead suctions dredging of fine-grained sediments.

All tests exhibited relatively fast flocculation and zone settling behavior in the saline solution as observed by a well developed water/soil interface within the first couple hours after the start of each test. Zone settling of these tests was usually completed within 24 hours at which point much slower self-weight consolidation settlement took place. A typical log-log plot of average concentration versus time is presented as Figure 2. Regression coefficients for self-weight consolidation (linear portion of the plot) were used to determine time dependent bulking factors and settlement rates.

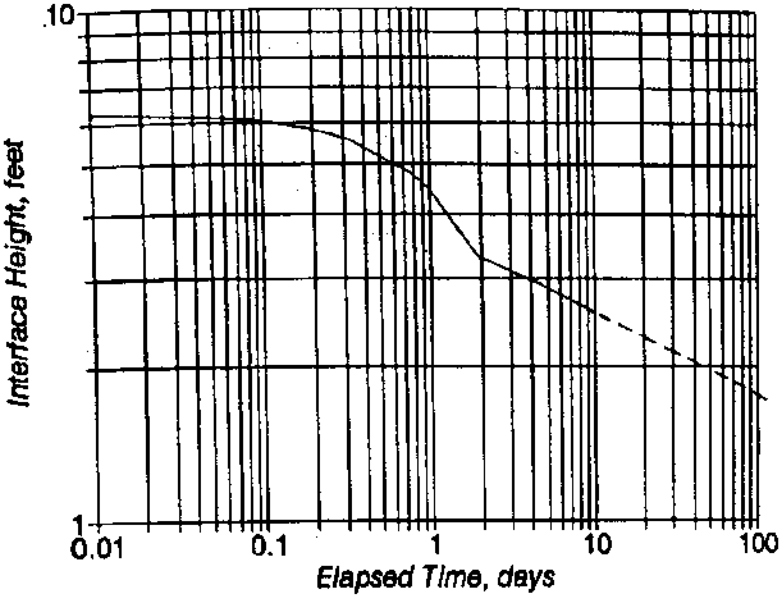

Figure 2. Large Diameter Column Settlement Test Results

Bulking Factors

Bulking factors are determined based on the volume ratio of bulked material to the insitu material. Time dependent bulking factors are a function of actual dredging methods and equipment, dredging rates, sediment concentration, salinity, and soil composition. Column settling test results were used to develop ranges of initial bulking factors based on various dredging phases and disposal scenarios. The following initial bulking factors were estimated for 3 and 5 month disposal periods.

Material	3 Month Disposal	5 Month Disposal
Fine-Grained	140 (± 15) %	130 (± 15) %
Sands	25 (± 10) %	25 (± 10) %

Central Basin Settlement Analyses

Large deformation consolidation settlement analyses conformed to finite-strain theory (USACE, 1987). Conventional 1-D consolidation for normally- and overconsolidated-soils is termed finite-stress theory. The settlement analyses require the use of nonlinear void ratio, vertical effective stress, and permeability relationships for highly bulked sediments. Degree of consolidation versus time analyses were performed to estimate gravity induced finite-strain consolidation coefficients (g_c) using the singly-drained column settling tests results. For the bulked sediments g_c was estimated to be about 0.0003 to 0.0007 ft²/day with an average of 0.0005 ft²/day.

Analyses included an iterative procedure using reduced coordinates for 10 layers of fine-grained material overlying a single bottom sandy layer. Additional settlement analysis was performed using the finite-difference computer program PCDDF89 (USACE, 1991). PCDDF89 simulates an incremental time-step primary consolidation process using finite-strain theory. PCDDF89 allows additional layers of dredge material to be added at any time to evaluate phasing of dredge activities.

Sand Cap

A 2-foot thick sand cap was planned for the CB. However, highly bulked, very soft, under-consolidated sediments have a very low bearing capacity (consistency of thick ketchup). This material would not support the proposed sand cap if placed too quickly causing mudwaves and uncontrolled sinking of the sand cap. It was estimated that the very soft materials would be able to receive only very thin applications of the sand cap material no sooner than about 1 month after the end of dredging. The specified rate of sand cap placement was such that no more than 3 inches of sand could be placed in a given area each day and that no more than 6 inches of unbalanced sand loading should be allowed. Observations indicated that the placed sand cap is adequately supported.

Dredging Contingencies

Uncertainties associated with the actual dredging rates, initial slurry concentrations, dredging sequencing, and variable sediment characteristics made analyses of the bulking factors and settlement rates difficult. Therefore phased dredging alternatives and contingencies were evaluated by the design team. If actual bulking factors were too high or if settlement rates were too slow, then it was planned to install closely spaced prefabricated composite vertical wick drains to accelerate the rate of settlement. Conversely, if the bulking factors were too low or settlement rates were too fast, then additional sediments could be dredged and placed in the CB to make up the short-fall. Luckily, the use of dredging contingencies for the project was not required.

Settlement Monitoring

CB settlement monitoring was performed using integrated digital multi-channel bathymetric survey and GPS equipment. Sequential settlement surveys were used to settlement rates and predict the CB surface elevations at various times in the future. Currently, a little over one year has past since placement of the sand cap and comparison of actual versus refined surface elevation predictions indicate good agreement. It is estimated that the sand cap surface will be at an elevation of -5 to -7 feet NGVD in 10 years. However, external sources of sedimentation and erosion may impact the actual future surface elevation.

Railroad Trestle Retrofit

The railroad trestle was originally constructed after the turn of the century using high quality round tapered Douglas Fir timber piles. The trestle consists of ballasted deck supported by steel stringers with wide flange capping beams on each pile bent. The typical symmetrical 6-pile bent has 2 vertical piles and four splayed battered piles (Figure 3). The trestle is 310 feet long and supports a single track at an elevation of +23 to +24 feet NGVD. Dredging beneath the trestle was planned at elevation -8.5 feet NGVD and therefore required an assessment of structural conditions of the trestle.

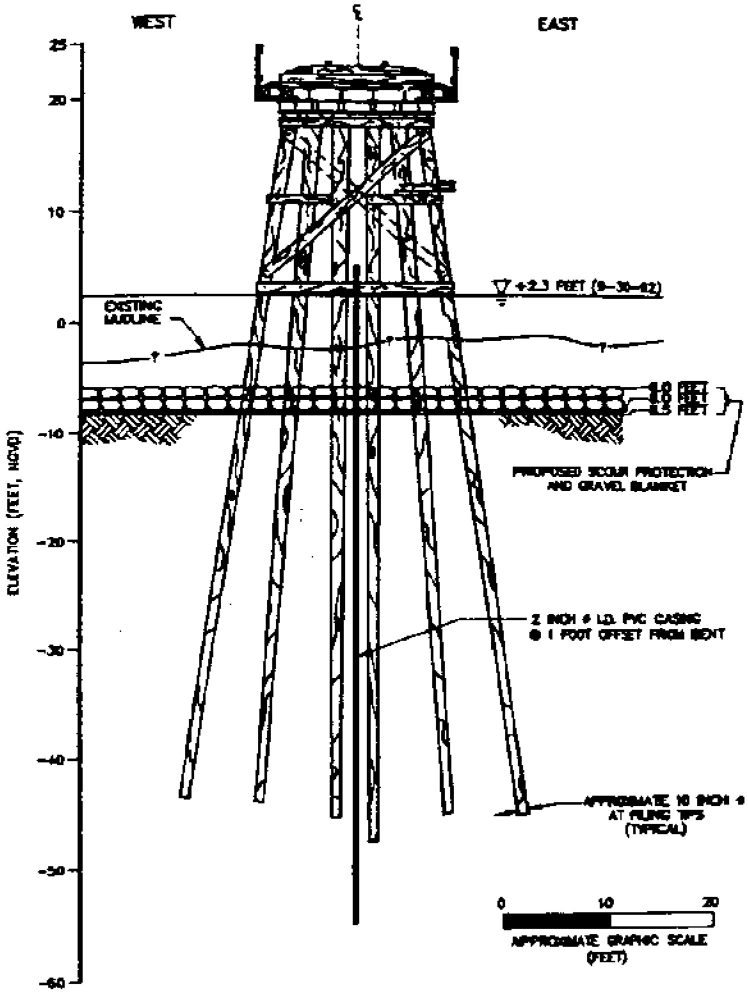

Figure 3. Railroad Trestle Cross Section

Parallel-Seismic Geophysical Testing

As-built plans for the trestle did not indicate pile depths. Therefore, nondestructive parallel-seismic (PS) geophysical testing was conducted to evaluate structural integrity, embedment lengths, and elastic moduli of the piles. PS tests consisted of using a wireline hydrophone receiver lowered into a water filled cased borehole adjacent to selected pilings to measure the arrival times of induced compression waves. The PS method involves impacting the pile top with a triggering hammer to generate a compression wave down the pile. The pile depth is determined by plotting the arrival times of the wave to the hydrophone receiver at predetermined elevations. When the hydrophone receiver is above the pile tip the compression wave arrival time is controlled by the compression wave velocity of the pile. After the compression wave reaches the pile tip, the wave arrival time is controlled by the compression wave velocity of the soil. Best fit regression analyses of the wave arrival time data allows for the determination of the pile tip elevation (Figure 4).

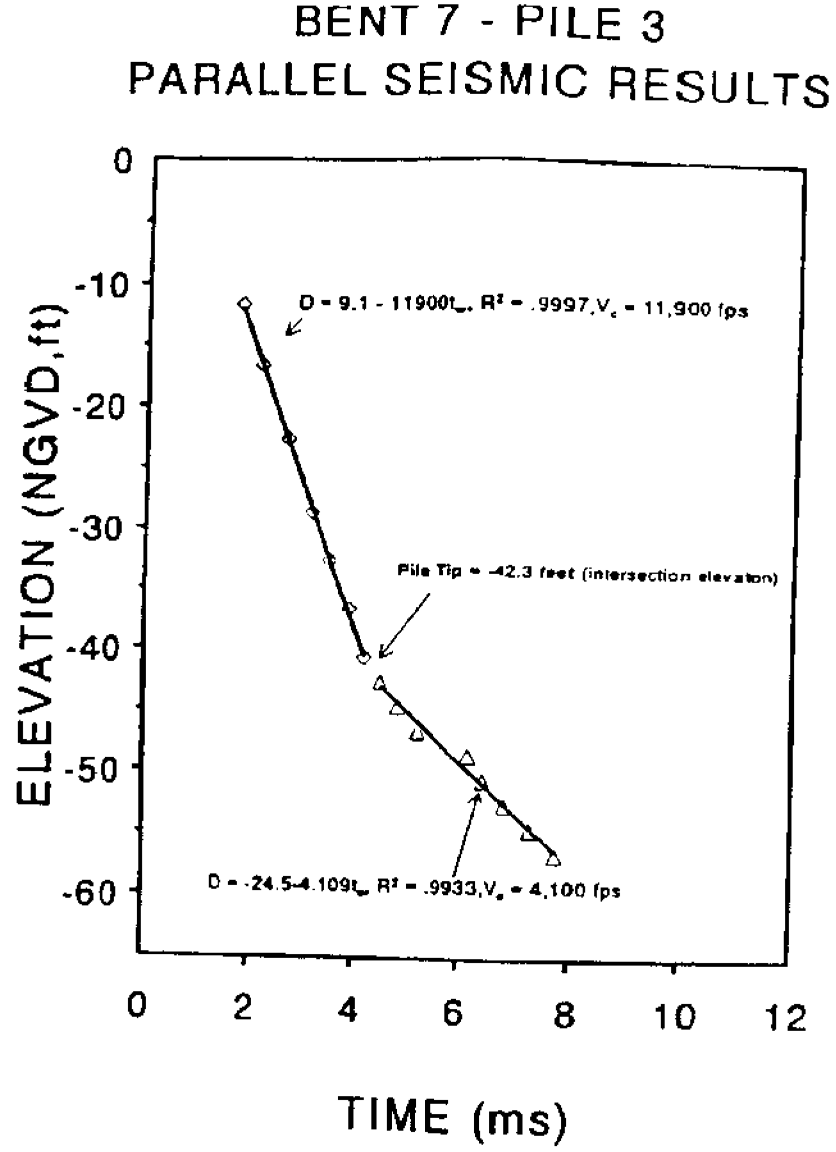

Figure 4. Parallel Seismic Test Results

Limited access drilling below the trestle centerline at 4 locations was performed to obtain soil samples and install 2-inch ID Schedule 40 PVC casings for the PS tests. Drilling consisted of 8-inch hollow stem auger borings to elevations ranging from -47 to -59 feet NGVD which were believed to be below the anticipated pile tip elevations. PS testing was conducted on a total of 24 piles and clearly indicated that vertical and battered pile tip elevations for the trestle ranged between -40 and -50 feet NGVD. Compression wave velocities of the timber piles were about 10,900 fps which indicates dense wood in very good condition (E = 2,000,000 psi). Measured piles butt diameters ranged from 14 to 19 inches. The average rate of pile taper was 0.088 in/ft with an average pile tip diameter is about 10 inches.

A discussion on the results of analyses for the effects of dredging, liquefaction potential, axial and lateral pile capacities, equivalent depth of fixity, settlements, and seismic retrofitting requirements for the trestle are beyond the scope of this article. However, it can be unequivocally stated that PS testing had the most geotechnical bang-for-the-buck for the project. Without the use of PS test results, very expensive retrofitting alternatives or replacement of the railroad trestle could have been required.

ACKNOWLEDGMENTS

The POLA's planned mitigations and restoration measures were authorized through interagency agreements and permits from the City of Carlsbad, California Coastal Commission, California Department of Boating and Waterways, California Department of Fish and Game, California State Lands Commission, Environmental Protection Agency, National Marine Fisheries Service, U.S. Army Corps of Engineers, and U.S. Fish and Wildlife Service.

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OCEAN BEACH, SAN FRANCISCO: PROTECTION AND MANAGEMENT OF AN ERODING SHORELINE

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ABSTRACT

Over the years, various reaches of Ocean Beach, a 3.6 mile long beach located along the Pacific coast of San Francisco between the Cliff House and the Fort Funston cliffs, have suffered erosion at intermittent times and several seawalls have been installed in these locations. During the 1994/95 winter storm season, severe erosion occurred along an unprotected reach between Sloat Blvd. and the Fort Funston cliffs. A temporary revetment was designed to address the immediate threat that this erosion represents to the Great Highway and other City of San Francisco infrastructure. This revetment was designed to be temporary and to provide protection until a permanent seawall could be funded and built. Design of the revetment, a hybrid design that uses concrete-filled geotextile bags and a buried quarrystone scour apron, involved coordination with various agencies, in particular, the National Park Service, who owns the beach on which the erosion is occurring. The revetment was designed using relaxed designed criteria so that it could be constructed using the funds available, but still provide temporary protection to the most critical areas. Because relaxed criteria were used, there will be a higher risk of damage to the structure, and as such, a monitoring and emergency response plan is being developed to provide guidance for monitoring the protected and unprotected sections in this reach and to provide a framework for response to future erosion.

INTRODUCTION

Erosion along a 2,700 foot reach in the southern portion of Ocean Beach, San Francisco, is a threat to valuable City infrastructure including: the 4-lane Great Highway running alongside of Ocean Beach; the Lake Merced Tunnel, a 14-foot diameter conduit beneath the highway south of Sloat Boulevard that transports combined stormwater and wastewater to the Oceanside Water Pollution Control Plant; and, if left unchecked, the recently constructed Oceanside Plant itself.

With an eye toward managing the risk of future erosion, the City and County of San Francisco (the City), in a joint project with the U.S. Army Corps of Engineers (USACE), had a comprehensive investigation made into the beach processes along Ocean Beach, with special emphasis on the reach south of Sloat Boulevard. The final report was issued in September 1996 (USACE 1996), and discusses the entire range of concerns with a major shore protection project including: biological and environmental effects, physical and engineering aspects, sociological impacts, and economic considerations. The report concludes with the recommendation for a permanent seawall to be constructed along the reach of Ocean Beach south of Sloat Boulevard. The City is presently pursuing funding for the design and construction of a permanent seawall along this reach of Ocean Beach.

Recent storm events that have led to accelerated local erosion of the bluffs in this reach and loss of portions of a parking lot and walking path above the bluffs, prompted the City to design and install shoreline protection measures that could be constructed to protect the shoreline until a permanent seawall can be constructed.

The design of these measures was atypical in that they were purposefully designed with limited design-lives in order to be built within the City's imposed budgetary constraints, to be easily dismantled or incorporated into the permanent seawall at the time it is constructed, and to meet other agency-specified requirements. There is a higher potential for damage to these shoreline protection measures and, therefore, a monitoring and maintenance/emergency response plan was an important part of this project.

This paper describes the design of these temporary measures and includes:

- A description of historic and continuing shoreline changes at Ocean Beach
- A discussion of the need for a temporary structure
- The project guidelines and regulatory agency approvals needed to implement the project
- A description of the shoreline protection measures designed for short-term protection of the bluffs and City infrastructure behind the bluffs
- A description of key components of a monitoring and emergency plan developed to monitor the performance of the structure and respond to future erosion in the area.

Shoreline Change at Ocean Beach

Shore erosion is a recurring problem along Ocean Beach — a 3.6 mile long coastline of continuous beach with intermittent dunes and low bluffs, forming the westernmost limit of the City of San Francisco (Figure 1). The entire beach is open to direct wave attack from the Pacific Ocean.

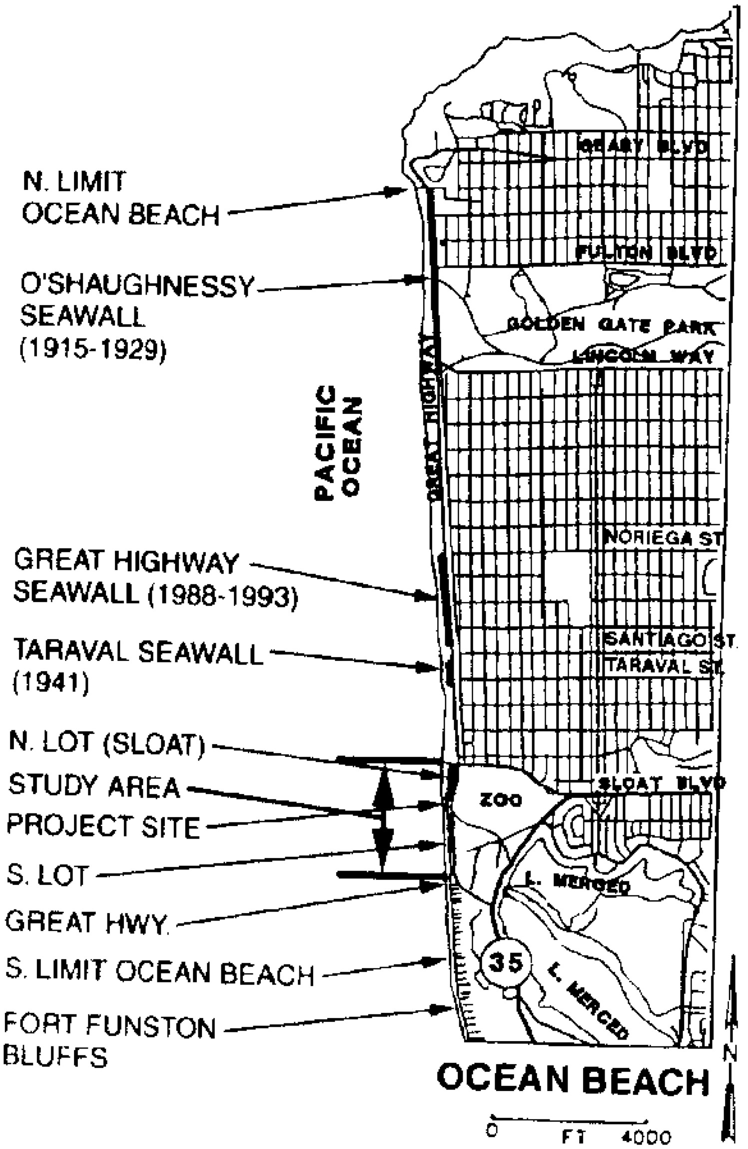


Figure 1 Shore Erosion Along Ocean Beach

Changes in the shoreline and beach profiles at Ocean Beach are complex in that they are influenced by both natural events and human activities. As such, conclusions about future changes in the shoreline based on historical, averaged data are difficult and can be misleading. In addition to direct impacts on the shoreline due to activities such as road and seawall construction, indirect activities that affect the erosion and accretion patterns of the shoreline along Ocean Beach include beach nourishment, sand mining (stopped in 1967), and changes in the offshore San Francisco Bar from dumping of dredge sands (Moffat and Nichol 1995). All of these have influenced the patterns of erosion along Ocean Beach.

Historic Response to Erosion

Since the late 1800s, man has extended the natural shoreline along the west coast of San Francisco seaward 200-250 feet through the deposition of imported sand, soils, and construction debris largely during the construction of the Great Highway that runs the length of Ocean Beach. Additional material was deposited from local construction projects, such as the Oceanside Water Pollution Control Plant at the south end of Ocean Beach and the Westside Sewage Transport Box under the Great Highway north of Sloat Boulevard.

Episodic shoreline retreat and beach erosion has affected much of Ocean Beach ever since man began his modifications to the coastline and has threatened or damaged infrastructure constructed along the coastline since the 1890s.

O'Shaughnessy Seawall - In response to early erosion, the City constructed the 4,600 foot-long curved concrete O'Shaughnessy Seawall at the north end of Ocean Beach between 1915 and 1929. This seawall was originally planned to be constructed along the entire Ocean Beach shoreline to protect the highway and to make a boardwalk/amusement tourist area. Economic conditions halted the project in 1929 (USACE 1996). This structure has prevented the loss of an extensive promenade and the adjacent Great Highway located next to the seawall.

Taraval Seawall - Erosion 8,000 feet south of the south end of the O'Shaughnessy Seawall in 1931 and 1939 caused damage to a pedestrian tunnel under the highway at Taraval Street. The City constructed the 662 foot-long Taraval Seawall in 1941 to protect this underpass (Berrigan 1985, Weggel 1988). This seawall is a 3-sided steel sheet pile structure with a concrete cap that remains buried except during periods of high waves and tides. In November 1983, the top 2 feet or so of the cap was uncovered during a major coastal erosion event. Aside from this event, the Taraval Seawall is normally covered in sand and has performed well in protecting the reach behind the structure.

Great Highway Seawall - The latest seawall was installed from 1987-1993 starting 4,400 feet south of the O'Shaughnessy Seawall for a 2,900 foot reach (Moffatt and Nichol 1995). This seawall was needed to prevent damage to the highway and the Westside Transport Box then under construction. (The Westside Transport Box is a conduit beneath the Great Highway that delivers sewage and stormwater to the Westside Pump Station at Sloat Boulevard.)

Beach Nourishment - Beach nourishment using excavated sand from construction projects adjacent to Ocean Beach and from off-site locations in the early years of development have had various degrees of success, depending on localized beach erosion processes. Windblown sand has been a persistent problem along much of Ocean Beach north of Sloat Boulevard, particularly along the O'Shaughnessy Seawall and intermittent areas south of there. The City, under a special use permit with the National Park Service, has been removing excess sand from these areas since the early 1980s and nourishing the beach areas where erosion has been a problem. The latest beach nourishment in the area south of Sloat Boulevard was in 1994 and consisted of 25,000 cubic yards of sand being placed on a 1V:3H slope adjacent to the south parking lot located alongside the western lane of the highway. This sand has almost completely eroded away since then.

Erosion and Accretion Along Ocean Beach

As mentioned above, evaluation of long-term erosional and accretional trends along Ocean Beach is difficult due to limitations of the existing database, effects of construction along the coast and other human activities that can influence the sediment loads in the system. Short-term changes can be significantly influenced by episodic events such as storms during the 1994/1995 season that caused 30 to 40 feet of retreat in the bluffs in areas south of Sloat Boulevard over the course of a few days.

Both long- and near-term changes at Ocean Beach are discussed below. Although long-term changes are important for planning and design of shore protection projects, it is the potential of near-term changes such as those that occurred during 1994/1995 that needs to be considered in decisions to implement immediate shore protection in the study area.

Long-term Trends

Figure 2 reproduces sediment transport patterns postulated in Moffat & Nichol (1995) based on a synthesis of available data. Sources of sand that have been associated with

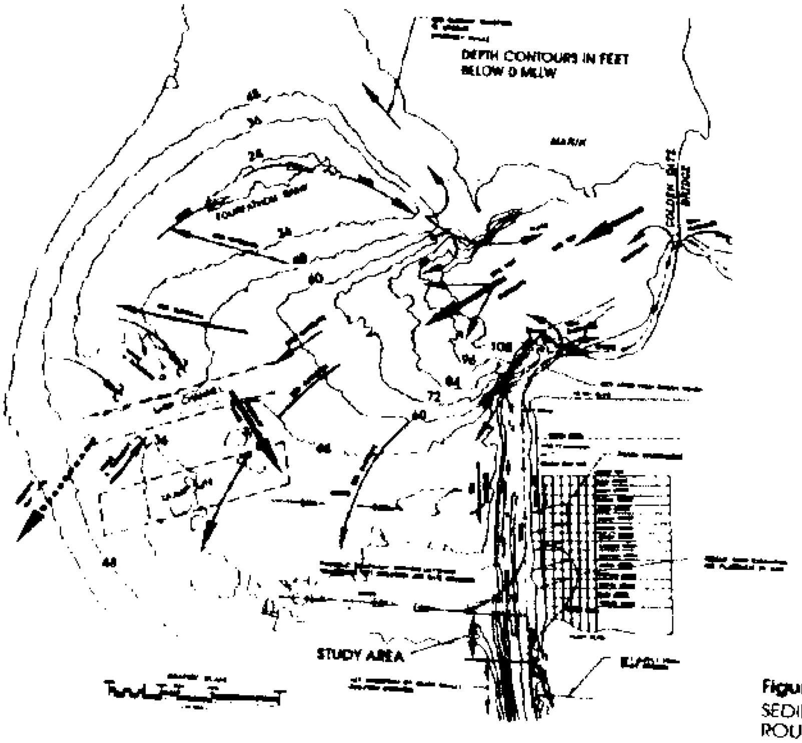


Figure 2
SEDIMENT TRANSPORT
ROUTES AT OCEAN BEACH
(From Moffat & Nichol, 1995)

Ocean Beach include sediment that is transported shoreward from the San Francisco bar that lies offshore from Ocean Beach. In addition to sediment carried from the bay and deposited on the bar with ebb tides, additional sediments dredged from the bay and from the ship channel leading into the bay have historically been disposed of onto the bar just south of the ship channel. Erosion of the Fort Funston cliffs approximately 0.6 miles south of Sloat Boulevard also contribute to the sand supply.

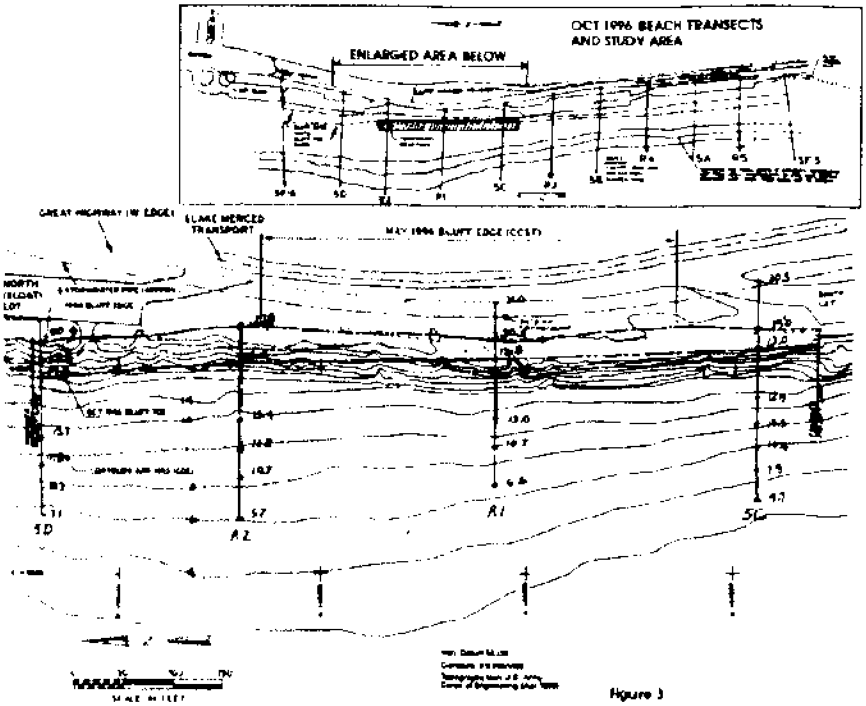
Beach changes at Ocean Beach can be affected by a number of factors, including the offshore bar, sediment transport patterns, storm paths, sea level rise (both short term as with El Niño events and long term eustatic rises), and localized vertical movements of the coast. For the area south of Sloat Boulevard, the trend, as much as it can be ascertained, is for continued erosion of the beach.

Average long-term trends in the study area south of Sloat Boulevard, based on shoreline mapping and photogrammetry from 1929-1992, indicate an average bluff toe advance of 1-foot per year along a reach extending 2,500 feet south of Sloat Boulevard and the retreat of 1-foot per year in the reach just south of that. The long-term advance may have more to do with man-induced changes than natural processes. Even if this is a real advance, these potential long-term gains have been overshadowed by near-term losses due to recent storm events.

Near-Term Trends

Near-term shoreline changes were addressed by Moffatt and Nichol (1995) using beach width as a measure of the changes. It was concluded that there was a high probability that the beach width could decrease significantly from what it was in 1993, the last year of topographic data used in their study. The typical beach width then of 175 feet underwent seasonal decreases of 50 feet, and fluctuations of 150 feet had been observed. The study concluded that the beach in front of the area of concern could disappear completely during a future storm event. Waves running up the much diminished beach would then impact and erode the bluff slopes.

Indeed, the erosion of 1994/1995 has born out the concerns in earlier studies. A series of surveys by the City has documented the changes since April 1993. Unfortunately, none of the beach transects made by the Corps of Engineers in 1993 aligned with those made by the City in 1995 and 1996. Figure 3 shows locations of survey transects made by the City within the study area superimposed on top of a topographic map generated



TRANSECTS WITH SPOT ELEV. ARE FROM OCT 1996 CCSF SURVEY

Figure 3
BEACH SURVEY TRANSECTS AND PROJECT AREA

based on the Corps 1993 survey. Changes in the shoreline topography for the reach between the two parking lots can be seen by comparing spot elevations near the bluffs from the City's survey with contours from the Corps survey. Figure 4 shows profiles of the beach transects surveyed by the City from August 1995, April 1996, and October 1996 compared with cross sections scaled from the USACE April 1993 mapping. It is readily apparent that dramatic erosion has taken place between 1993 and the present.

The present bluff and beach profile at survey transect R1 (based on the 1996 survey) represents a typical cross section for the heavily eroded area between the two parking lots and is shown in Figure 5 in relation to the Great Highway, Lake Merced Tunnel, and the storm drain for the Great Highway. The scaled profile from the Army Corps of Engineers April 1993 mapping is superimposed for comparison. All elevations are in feet MLLW datum.

The National Park Service in August 1996 smoothed the bluff slope from approximately 200 feet north of the entrance to South Lot to the south end of South Lot to rid the area of unsightly remains of the destroyed steps and pathway including the slope at transect R1. These changes in the bluff slope at R1 were small and are not shown in Figure 4.

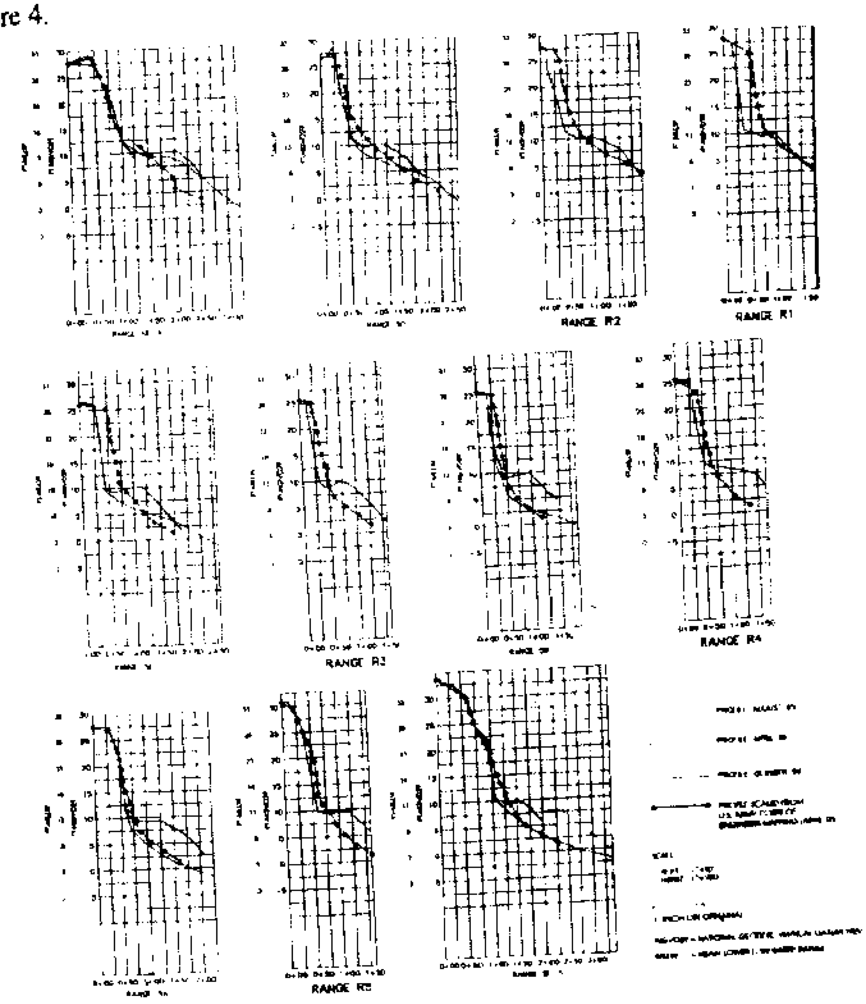


Figure 4
1995 - 1996 BEACH SURVEY TRANSECTS AND 1993 BEACH PROFILES

Potential Future Changes

For an eroding beach under the action of storms and complex breaking wave patterns, year to year changes in beach topography cannot be predicted with any certainty. The amount of erosion in a given year depends on a large part on the severity of the winter storms in the North Pacific Ocean. It is appropriate to address potential future beach profiles based on probabilities.

The estimated return-period dune or bluff toe retreat for any given point on Ocean Beach in a single storm season based on projections in USACE (1992) is shown as the lowest curve in Figure 6. Based on this curve, there is about a 5% chance that 25 feet or more of toe retreat will be experienced in any one year. The other curves were developed from the 1-year curve and are for cumulative retreats over 2-, 3-, 5-, and 10-year periods. For example, the curve labeled "2 years" presents the probability that the retreat over the

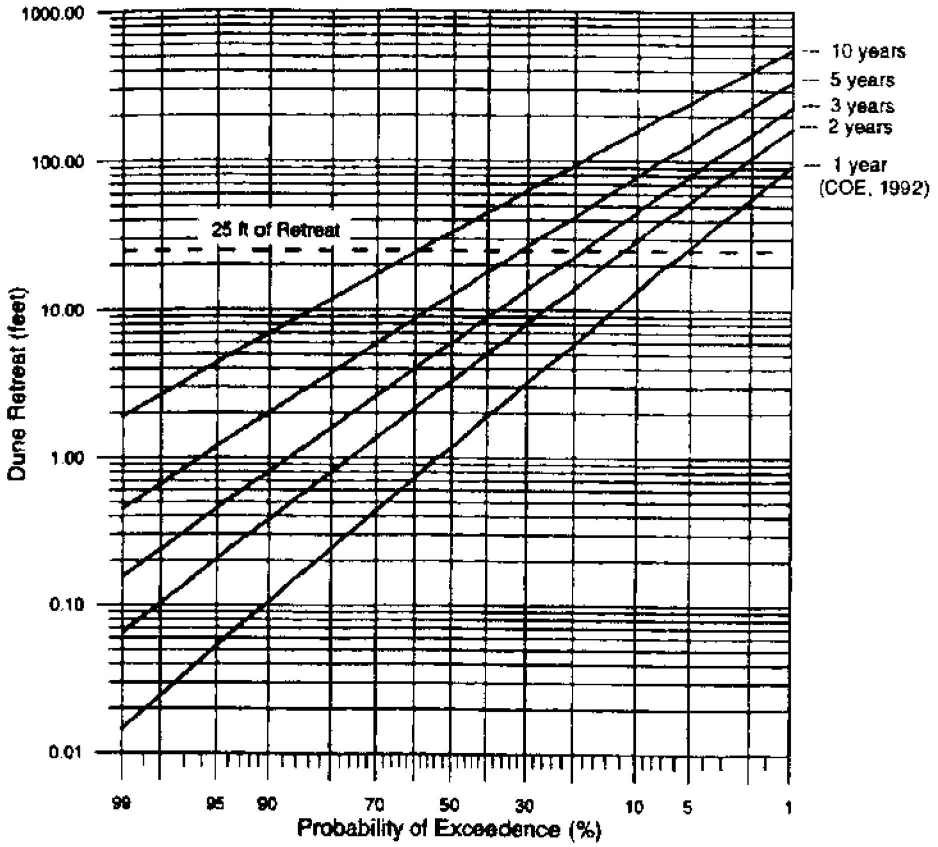


Figure 6

RETURN-PERIOD
BLUFF RETREAT

first year plus retreat over the second year will exceed a certain value. The dashed horizontal line represents a cumulative toe retreat of 25 feet, which approximated the remaining minimum distance between the bluff edge and the west edge of the highway in the area between the two parking lots at the start of the project. For a given time period, the probability of a 25 foot or greater toe retreat is:

1 year = 5%
2 years = 11%
3 years - 18%
5 years = 31%
10 years = 60%

Conversely, projected bluff toe positions can be estimated for given exceedence values. The projected location of the toe after an elapsed time of 10 years starting in 1993 is plotted on Figure 5, also. Bluff slope profiles are shown for probabilities of 16%, 30%,

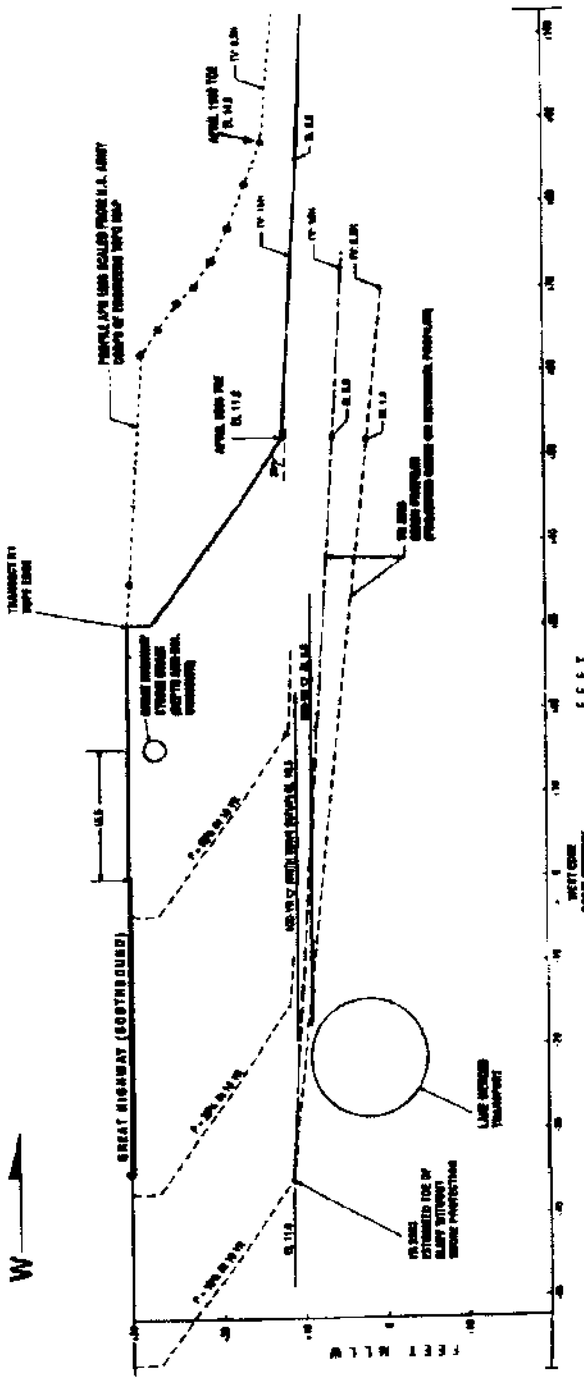


Figure 5
CROSS SECTION AT TRANSECT R1
THROUGH LAKE MERCED TRANSPORT

and 50% based on an 11.8 feet MLLW toe elevation for a typical wintertime beach. A worst-expected case for blusff recession was judged to be where the beach profile just touches the crown of the Lake Merced Transport box at its closest approach to the west edge of the highway. There is a 16% probability that this could happen by the year 2003.

The Need for Temporary Protection Measures

The study area, shown in Figures 1 and 3, was the reach from the north end of the North (Sloat) Parking Lot to the terminus of the sand access ramp with the beach at the south end of South Parking Lot. The bluffs in this area consist of a natural formation -- the Colma Formation -- consisting mostly of friable sand that is easily crumbled by hand. This foundation layer is covered with sand from both natural deposition and man's intermittent efforts at beach nourishment.

Like the rest of Ocean Beach, this area is tremendously popular to all types of beach goers -- surfers, surf fishers, sunbathers, joggers, and tourists. The two parking lots south of Sloat Boulevard had been constructed alongside the west lane of the Great Highway to provide parking and access to the beach below.

Recent shoreline retreats in the 2,700 foot reach from Sloat Boulevard south to the Fort Funston cliffs pose an imminent threat to this infrastructure. Waves and high tides in the winter of 1994/1995 eroded the shoreline, causing a 30-40 foot retreat and oversteepened much of the bluff slope over approximately a 2,200-foot reach. These events prompted the City to mitigate the erosion in the short term and to plan for a more permanent long-term solution to shore erosion.

The most pronounced shoreline retreat was found to be the 1,920-foot reach from approximately 550 feet south of Sloat Boulevard to 200 feet south of the south edge of the South Lot, and it was in this reach that the study concentrated.

In the erosional events of 1994/1995, the North Lot lost all 4 of its access stairways to the beach, and the bluff edge retreated to within 8 feet of the west edge of the parking area. At the South Lot, erosion destroyed 5 beach access stairways from the top of the bluff to the beach, but left intact riprap mounds of 700 pound median weight stones at each of the sites protruding 10-20 feet onto the beach. An asphalt pathway along the bluff fell onto the beach along with a storm drain conduit. Concrete debris has been exposed for several hundred feet in this area. Figures 7, 8, and 9 show the appearance of the project area in July 1996.

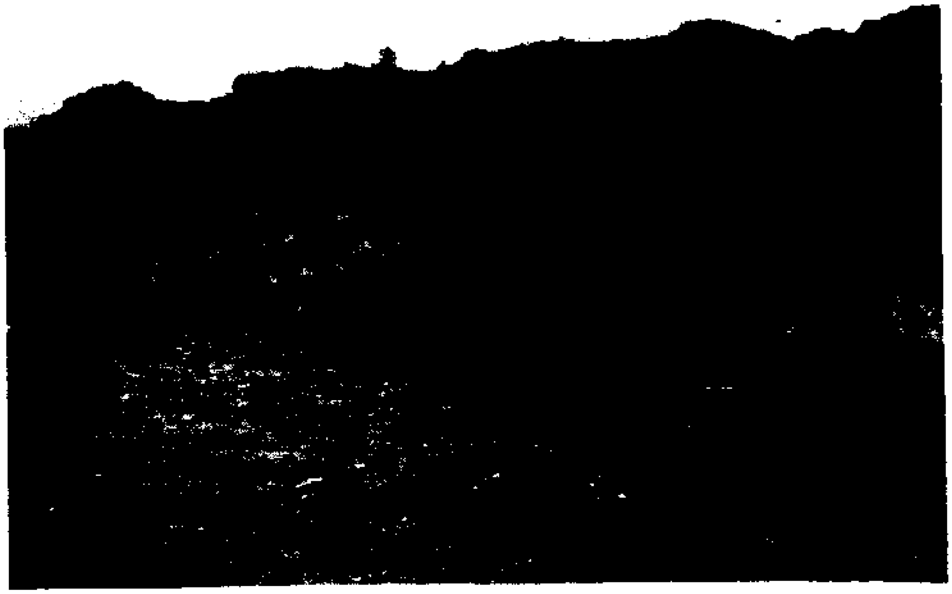
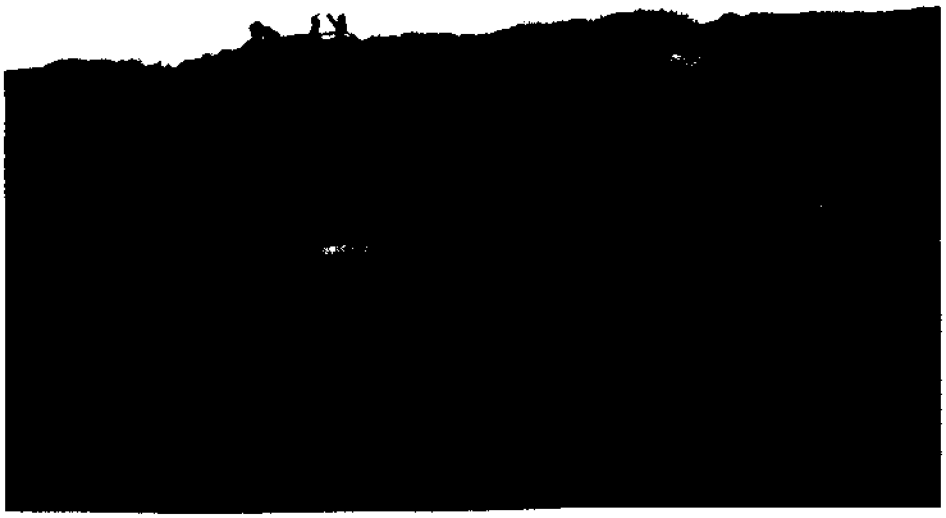


Figure 7

(Top) South limit of temporary shore protection is the riprap mound (right edge). Survey Transect 5C is at left edge of the photograph. (August 1996)

(Bottom) Bluff face about halfway between the two parking lots. Painted quarrystone near center of picture measures 4x4x6 feet. (August 1996)



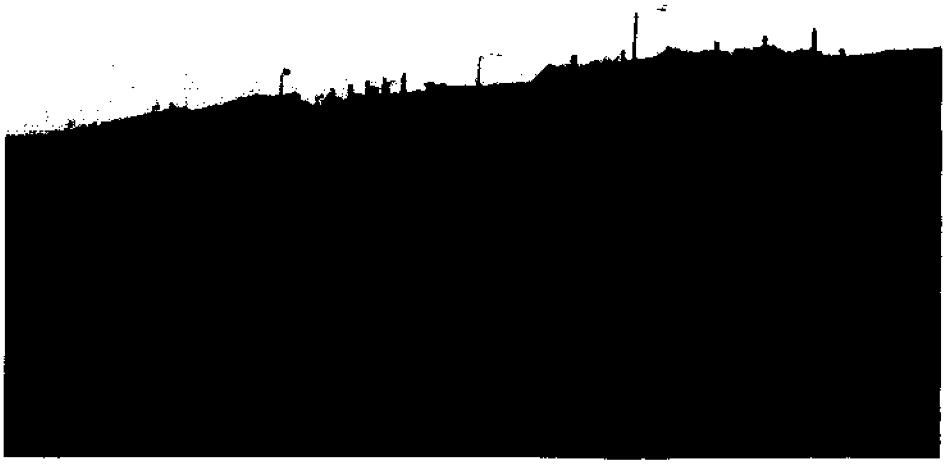


Figure 8

(Top) Eroded bluff with surfers about to descend the bluff slope to the beach. Stakes in the beach (right edge of photo) are at Survey Transect R1. (August 1996)

(Bottom) North limit of temporary shore protection at South (Sloat) Lot is at bluff toe at the far right fence post on the bluff's edge. Survey Transect R2 is 20 feet left of the beach stake. (August 1996)

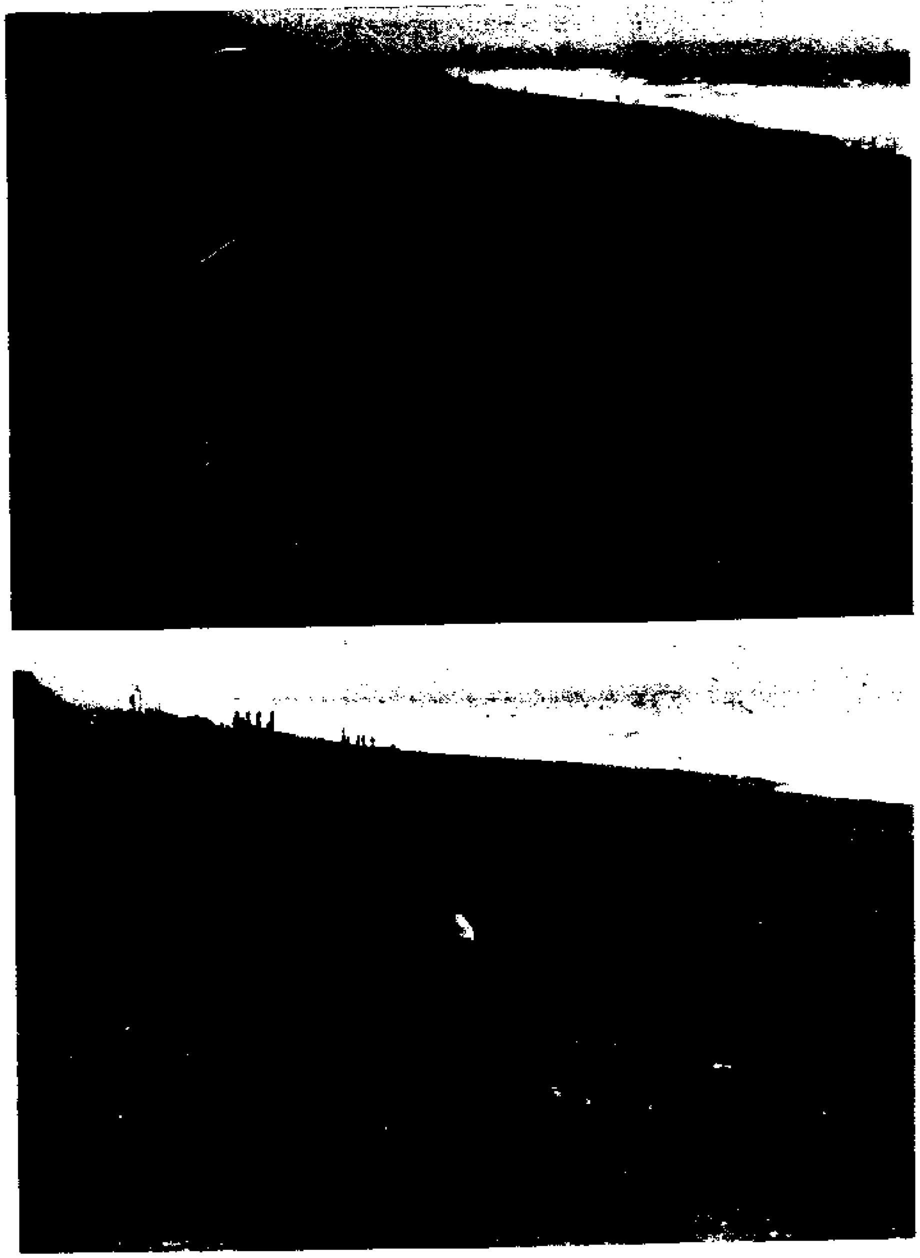


Figure 9
(Top) Looking South from South end of South Lot. The Great Highway is at the upper left, and the south limit of the temporary shore protection is the riprap mound at the bluff toe (top center). (August 1996)

(Bottom) Approximately 180 feet north of South Lot, looking South. South limit of temporary shore protection is the riprap mound at the damaged pathway to the beach. Concrete pipe (center) angled into the beach is an abandoned wastewater pipe.

In most areas, the bluff slope has been oversteepened to an angle of 40-70 degrees from the toe to a 12-15 foot distance above the toe where a vertical escarpment extends another 3-5 feet to the bluff edge.

Precipitation runoff and foot traffic has caused further erosion, with gullies extending landward of the typical bluff edge in the area between the two parking lots. In March 1997, one storm formed a gully that eroded up to approximately 15 feet further into the bluff. This erosional feature is shown in Figure 10. Due to these more recent events, the bluff edge is now less than 15 feet from the west edge of the Great Highway in one place between the two parking lots.

Figure 10

Additional [illegible] erosion from March 1997 storm

The immediate area of concern requiring shore protection is the 600-foot reach between the 2 parking lots, shown in Figure 3, where another event like those in 1994/1995 could damage the highway and the stormwater drain line that parallels the western edge of the pavement.

The Lake Merced Tunnel, shown below the highway in Figure 5, is located below the groundwater table. With loss of the overbearing material, buoyancy forces could lift and damage the concrete pipe unless it was ballasted with water inside the pipe. Provided that the pipe remained intact, further retreat of the bluff would be slowed or even halted once the beach level eroded below the crown, as the pipe would act as a "shore protection structure." It would be a catastrophic event for the beach to lower far enough that the pipe would be undercut, however it is not an event one would expect based on what is known about the area.

In the near-term, there is a one in two chance that the bluff will retreat inland far enough by the year 2003, that the storm drain and part of the Great Highway will be damaged without shore protection in the area between the two parking lots. The parking lots themselves also would be damaged or destroyed, but the highway and storm drain would be spared in these areas because they are further inland.

Project Guidelines/Agency Requirements
The need for immediate shore protection in the area between the two parking lots was of concern to the City, the National Park Service (NPS), the California Coastal Commission (CCC), and the U.S. Army Corps of Engineers (USACE). All of these agencies were consulted during initial portions of the study in order to develop appropriate project guidelines for the design and other agency requirements for implementation of the final solution.

Primary concerns and roles of each agency were:
The City - As lead agency for planning and funding the shore protection structure, the City was very concerned about damage to its infrastructure near the bluff and the adverse impacts loss of the highway or damage to the Lake Merced Transport box would have on the residents served by these public structures.

National Park Service (NPS) - In 1972, the City deeded the beach from the west edge of the right-of-way of the Great Highway to the NPS for incorporation into the Golden Gate National Recreation Area. Because of this, no action could be taken by the City beyond the western curb of the highway without full consent of the NPS. As such, the NPS was consulted throughout the design study with regards to their concerns on various design elements of the measures. As owner of the property on which the structure would be placed, NPS was interested in minimizing the impact that the structure would have on the natural appearance and behavior of the seashore. NPS also coordinated with the U.S. Fish and Wildlife Service regarding biological impacts including issues related to Snowy Plover nesting habitat north of the site and impacts to swallows that live in the Fort Funston cliffs.

The California Coastal Commission (CCC) - The CCC participated in the planning process to help ensure that the project would not affect public access to the beach and that the least intrusive means were used for erosion control.

Corps of Engineers (USACE) - USACE representatives were present at early coordination meetings, largely to ensure that the City understood their permitting requirements and timeframes so that the permit process would not become an obstacle to timely construction of the revetment. However, because the design of the revetment allowed all of the construction on the surface of the beach to be above Mean High Water, no USACE permit was required.

There were ample prior studies and recent large shoreline erosion to justify taking action for slowing or halting the retreat of the shoreline in the interest of preserving costly infrastructure. Further studies, although adding to the knowledge base, would only lengthen the time before action could be taken. Thus, the City made the decision to proceed as quickly as possible with the design of a temporary shore protection structure to be installed in the summer of 1997 until a permanent solution to the erosion could be put in place, which would involve a much longer process.

Throughout the design process, the City provided the NPS, CCC, and USACE information and drawings for their review and comments. Additionally, the California Department of Boating and Waterways provided review and comments on the proposed shore protection structure.

The following guidelines were developed for the design of the shoreline protection measures based on the concerns of the above agencies.

- Emphasis on Alternatives to Quarrystone - Determine if there are alternatives to quarrystone or riprap revetment structures that would be suitable for the site. An exposed quarrystone revetment should not be used unless it is the only feasible method. NPS considers that quarrystone revetments would pose a safety hazard to people walking on the stones and provide habitat for rats that could disturb the swallows inhabiting Fort Funston cliffs south of the South Lot.
- Temporary Structure - Structure should be temporary and designed with a 5-10 year life, and will be removed or incorporated into the permanent solution yet to be adopted for the site.
- Proven Methods - Selected alternative(s) should be proven methods used in similar high wave energy wave environments on open coasts.
- No Beach Nourishment - Beach nourishment should not be considered as an alternative. Since the site is an eroding beach, beach nourishment would be a recurring operation and would require costly maintenance and disruption of the ecology and public use of the area.
- Preserve Access - Access to and use of the recreational beach in front of the bluffs should be preserved to the fullest extent possible.
- Limited Protection - Near-term erosion protection shall be placed only as necessary to protect the Great Highway and buried infrastructure rather than along the entire 1920-foot reach. NPS considered that some damage to the parking lots would be acceptable.
- Construction Before Winter 1996/1997 - The design was to be constructable prior to the 1996/1997 winter storm season. (This was the original goal, but subsequent delays made it necessary to delay the planned installation until the summer or early fall of 1998.)
- Streamline Permits - A structure that can be constructed above MHW (5.3 feet MLLW) was preferred in order to reduce permitting requirements.

Shoreline Protection Design

The design of the shoreline protection was done in two parts:

An initial assessment was made of areas immediately in need of shoreline protection based on current (1996) site conditions. Identification and screening of alternatives was done to identify measures that would satisfy the project guidelines, and recommended alternatives were presented for protection of the areas of concern in the near-term.

Immediate shoreline protection design in which a short-term structure for arresting erosion in the most critical areas was designed.

The following presents the results of the alternative analysis from the initial assessment, the design of the temporary toe protection revetment (TTPR) designed for protection of the shoreline until a permanent seawall could be constructed, and the design of an interim measure to protect the bluffs from further erosion over the 1997/1998 winter storm season.

Alternatives Analysis

Extensive research into the suitability of alternative methods meeting the guidelines presented above showed that there were few alternatives that one would have confidence in at the site based on papers in the professional literature and USACE (1981, 1984, 1985). Each potential alternative was evaluated using the guidelines above as well as the following criteria:

- Availability of design criteria and practices.
- Survivability of the structure on an eroding beach in which the structure would be exposed to higher wave energy as the beach erodes.
- Performance of structures at other locations.
- Availability of materials to meet the construction schedule.
- Ease of construction.
- Construction cost.
- Maintenance.
- Beach "footprint". The smaller, the better.
- Aesthetics and beach access.

Table 1 shows the alternatives rejected during the initial screening and the reasons they were rejected. Six types of structures were considered for further review. These alternatives were deemed to meet all or most of the design criteria. These were: (1) Longard Tubes, (2) Patented Sand Container Systems, (3) Sandbags, (4) Quarrystone Revetment, (5) Geotextile Bag Revetment, and (6) Perched Beach.

TABLE 1. APPROACHES REJECTED DURING INITIAL EVALUATION

Alternative	Reason Alternative was not Considered
Field Stone	Stones have rounded edges, do not interlock well, may not be commonly available.
Asphalt	Poor survivability, unsightly
Concrete (Formed)	Cast-in-place seawall revetment. For long-term solutions
Gabions	Wire baskets or cages of rock are commonly used for slope protection where wave forces are small and on slopes to provide stability. Flexing of gabions in a strong wave environment result in shifting, toe failure, or broken cage wires and progressive failure as supporting gabions crumble and those on top slump down.
Fabric	Geotextile and other fabrics placed over a slope and weighted at top and bottom are only very temporary solutions to minor erosion problems. This method has a poor record for shore protection
Soil Cement	A mixture of Portland cement, water and soil is made and compacted in place, typically in stair-like fashion. This method has proved successful in lake environments and for reservoirs. When hardened, a rigid structure similar to concrete is formed. Oceanic coastal applications could not be located, and many uncertainties exist concerning its response to ocean waves and hydraulic pressures
Landing Mats	Fiberglass or concrete block or pillow-shaped mattresses. Various versions are commonly used along river banks and in low wave environments. They are not suitable for open coast applications
Vegetation	Rejected outright
Large Rock Overlay	A layer of large quarrystone placed over an existing damaged stone seawall revetment or to upgrade an existing revetment to accommodate larger wave forces. Stone weights are sized for the particular environment.
Concrete Revetment Blocks	Not suitable for high energy wave environments. Blocks interlock with each other, and failure of a few blocks can lead to progressive failure of the structure. Requires carefull subgrade preparation
Concrete-Filled Mattresses	Special concrete bags filled in place with concrete, row by row until a sloped wall is formed. Requires good subgrade preparation to prevent differential settlement of the inflexible wall once it hardens. Used in low wave environments
Steel Fuel Barrels	Unsightly and unsuitable for open coast applications.
Concrete Slabs	Concrete slabs placed on a prepared slope to form a smooth wall. Failure due to toe scour, hydraulic uplifting, and shifting caused by differential wave forces make this method unsuitable for open ocean coasts
Tire Mattresses	Unsightly and unsuitable for open coast applications.
Windrow	Stones stockpiled at edge of bluff or embankment and allowed to fall onto the beach below as erosion continues on the slope. Not suitable for Ocean Beach

These are presented and reviewed briefly below. The first three involve the use of soft or semi-rigid containers made of geotextile or nylon-type fabrics that are filled with wet sand. Based on the review the last three methods were considered the most viable means of shore protection at Ocean Beach.

Longard Tubes. Longard tubes may be 6 feet in diameter and 100 feet long. They are subject to damage from vandalism and debris impacts and are prone to shifting. Their use on an open coast was deemed to be impractical.

Patented Sand Container Systems. These are relatively recent inventions and have been used from Florida to New York and have provided protection during hurricane storm surge events (Harris 1988, 1989). These systems have compartmentalized chambers in the fabric tubes so that loss of sand from a damaged chamber does not lead to progressive failure of the whole structure. The tubes are affixed to a geotextile fabric mat that forms the scour apron. The entire structure is then covered with sand. At the present time, design criteria are based on experience of the designer and not established practices, but the science is evolving. Units also require special manufacture and strict monitoring to ensure they are correctly installed. Because of cost, timely availability, and the fact they would be placed on an eroding beach and become exposed to damage or vandalism, they were not considered a viable solution. Additionally, their performance under frequent wave attack on an open coastline was a concern.

Sandbags. Sandbags containing up to 4 cubic yards of sand have been used for slope protection on Arctic oil-rig artificial islands (Gadd, circa 1989) and in Southern California at Zuma Beach approximately 18 miles west of Santa Monica. Performance has been good, but Zuma Beach lies in a partially sheltered area east of the Channel Islands and in a region subject to much less frequent wave action. Cover sand must be kept over the bags to prevent vandalism or other damage. Sandbags were not considered to be a reliable means of shore protection at Ocean Beach.

Quarrystone Revetment. This is the best understood structure, as this method has been around for centuries, and extensive design practices exist. A preliminary analysis showed that a median armor stone weight of 4,600 pounds would be needed. As discussed above, quarrystone revetment designs were discouraged by NPS because they are felt to present safety hazards and provide habitat for rodents.

Geotextile Bags. These are similar to sandbags except they are constructed of geotextile material and are filled with concrete. Because they are concrete filled, they do not have the same potential for damage as the sand-filled concepts presented above. Geotextile bags are filled in-place, and when stacked, are relatively solid. Therefore, they do not present the safety hazards or potential rodent habitats that were associated with quarrystone. On the other hand, because they create a more solid surface, they do not have the same energy absorption characteristics of quarrystone.

Perched Beach. This design used a buried scour structure of armor stones approximately 25 feet seaward of the existing bluff toe, with median stone weights of 3,200 pounds. A toe revetment of concrete-filled, 2.2 cubic yard capacity geotextile bags would line the toe of the bluff to an elevation approximately 6 feet above the winter beach toe elevation.

A wave runup apron of Armorflex concrete mats on a 1V:2.5H prepared slope would extend from the top of the bags to 3-5 feet below the edge of the bluff. The scour apron and area between it and the bags would be covered in smooth pebbles and cobbles. The entire structure would then be covered with a layer of sand that would be eroded away in one or 2 winter seasons. Wave action on the pebbles and cobbles would provide wave energy absorption, yet still provide a walkable surface. A narrow strip of usable beach would still remain when the beach eroded lower in front of the scour apron.

The alternative selected for development was a hybrid revetment that incorporated geotextile bags along with limited amounts of quarrystone. The design, called the Temporary Toe Protection Revetment (TTPR), is described below.

Temporary Toe Protection Revetment Design

The structure that best met the design criteria above was a geotextile bag revetment that incorporated limited amounts of quarrystone. This design is refered to below as the Temporary Toe Protection Revetment or TTPR. This was the structure that all the organizations adopted as the approach to use. The preliminary versions in CH2M HILL (1996) were modified in response to cost considerations and more refined analyses during the design process. Table 2 lists the design basis for this temporary structure with the understanding that more stringent criteria would have been used for a permanent structure.

TABLE 2. DESIGN PARAMETERS FOR THE OCEAN BEACH TEMPORARY TOE PROTECTION REVETMENT.

Parameter	Value	Required for:
Water Surface Elevations		
Stillwater Elevation (astronomical tide + storm surge)	8.8 ft MLLW	Wave Runup Calculations
Water Elevation (SWL + 1.5 ft wave setup)	10.3 ft MLLW	Calculating Maximum Breaking Wave Height
Max. Design Water Depth at the Seaward Face of Scour Apron	5.3 ft	Calculating Maximum Breaking Wave Height
Design Waves		
Significant Wave Height, Hs and Period	19.0 ft (16.6 sec)	Sizing Structural Elements and Wave Runup Calculations
$H_{2\%}$ and Period (Average of highest 2% waves)	29.5 ft (16.6 sec)	Sizing Structural Elements and Wave Runup Calculations
Max. Design Breaking Wave Height (1)	8.6 ft	Sizing Structural Elements
Structural Characteristics		
A-Stone Size	50% of stones ≥ 2700 lbs	Structure Stability under design conditions
Geotextile Bag Size (Filled with concrete)	2 ft H x 6 ft W x 10 ft L	Structure Stability under design conditions
B-Stone Size	50% of stones ≥ 270 lbs	Structure Stability under design conditions
Maximum Runup Elevation	20.0 ft MLLW	Elevation of top of runup apron to prevent backshore erosion from waves

(1) The maximum design breaking wave height is calculated based on a 16.6 second period wave and a 1V:15H beach slope at the structure toe. For a wave with this height, it is expected that 0 to 5% of A-stones will be displaced.

A plan view of the TTPR is shown in Figure 11. The main body of the revetment would be 570 feet long with an additional 20-foot length of structure at both ends for transition

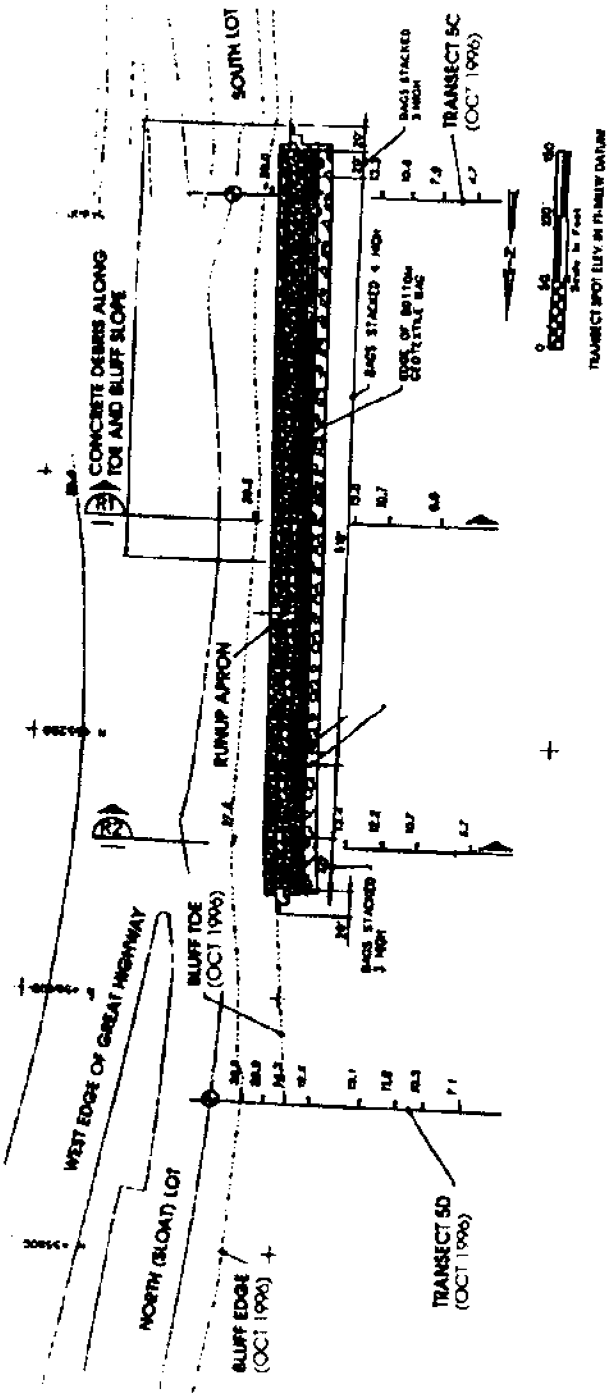


Figure 11
PLAN VIEW OF THE TEMPORARY TOE PROTECTION REVETMENT

to the natural surroundings. A cross section at beach transect R1 is shown in Figure 12 and is typical of the main body of the TTPR. The structure would require approximately

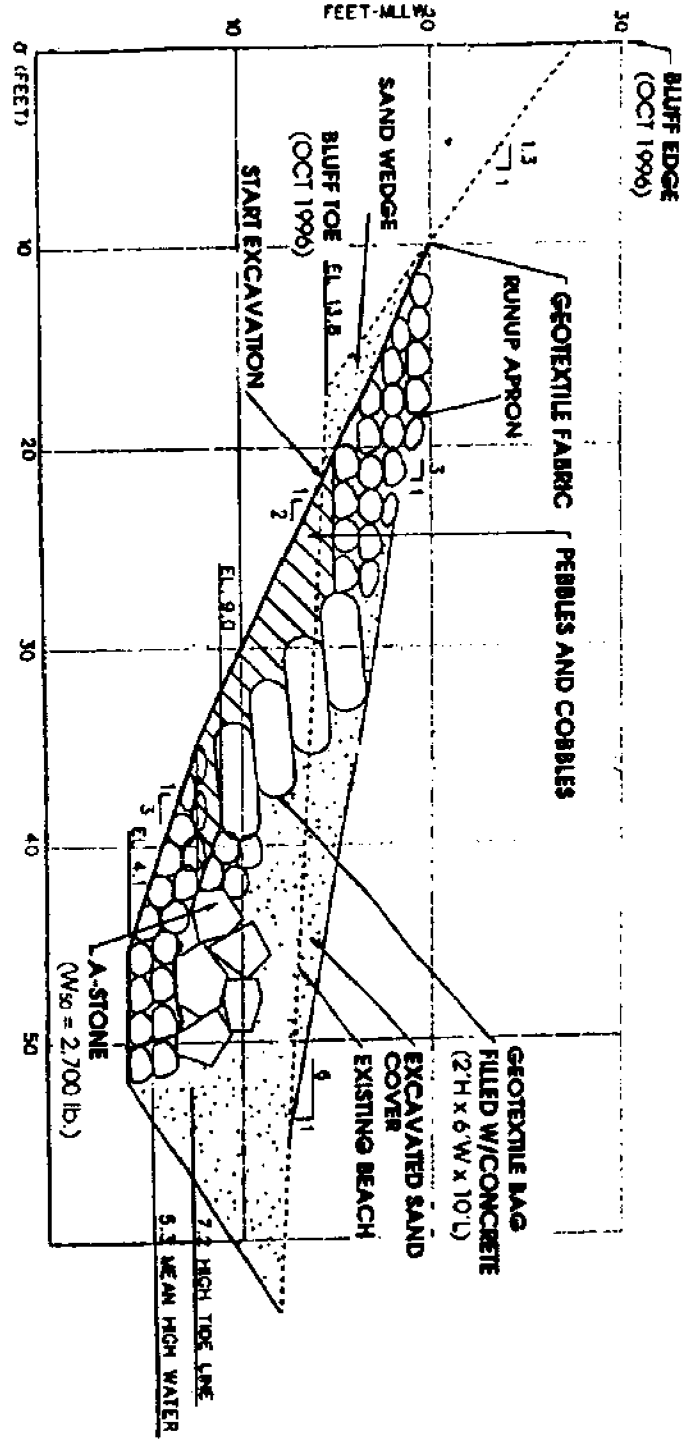


Figure 12
SECTION AT TRANSECT R1 OF THE
TEMPORARY TOE PROTECTION REVETMENT

the following material quantities.

Class A-Stones (median wt. 2,700 lb)	1,070	tons
Class B-stones (median wt. 270 lb)	1,840	tons
Pebbles and Cobbles	1,190	tons
Geotextile Bags (4.1 CY capacity)	236	bags
Concrete for Bags	930	CY
Geotextile Filter Fabric	31,950	SF
Sand Excavation and Backfill	4,600	CY

It was anticipated that the beach could erode below the crest of the A-stones in the scour apron fronting the geotextile bags, with the eroded beach toe lying along the face of the bottom row of A-stones. At this point, wave action would greatly increase at the structure as the higher high tides would reach the bottom row of A-stones if the beach erodes far enough. The TTPR was designed with the assumption that the permanent seawall would be installed before the beach erodes below the bottom row of A-stones in the scour apron. Static stability analyses showed that the geotextile bags will remain in place without any A-stones in the scour apron. However, the dynamic response of the structure would cause downward shifting of the bags when the B-stones began to displace under wave action. The structure, however, can be reinforced in response to an eroding beach if the permanent structure is not built in time.

As designed, the estimated construction cost of the TTPR in 1996 dollars was $680 per linear foot of beach width, using a 10% adjustment for general conditions and 20% for contingency.

Only minimal dewatering effort using pumps to remove excess water from the excavation was assumed, with no cofferdams or sheet piles being placed. If more extensive dewatering is required, the cost estimate would be considerably more. It was anticipated that construction would be "in the wet" to the top layer of B-stone or even the top of the pebbles and cobbles under the bottom row of geotextile bags, especially at tide elevations higher than 4.1 feet MLLW. The exact location of the groundwater table and its response to tidal action is not known for the site.

STORM SEASON 1997 TEMPORARY REVETMENT DESIGN

Delays made it apparent that the TTPR could not be constructed until 1998. CH2M HILL advised the City in July 1997 of the increased risk of erosion in the 1997/1998 winter because of the El Niño event developing along the eastern Pacific, as well as the increase in the number of higher high tides starting in 1998 through 2013 compared to a nadir in 1997.

In 1983, another major El Niño event comparable to the ongoing one was associated with the highest water levels ever measured in the San Francisco region (8.7 feet MLLW at the Presidio on January 27, 1983), which was 2 feet above the predicted high tide elevation. Major shore erosion occurred along certain reaches of Ocean Beach, particularly off Taraval Street (the extent of erosion south of Sloat Boulevard was not documented). If this storm surge had coincided with a predicted tide of 7 feet or more, the resulting erosion at Ocean Beach would likely have been much worse.

The City and the NPS recognized that a higher than normal risk of substantial erosion was possible in the 1997/1998 storm season. A low cost, easy-to-install design was prepared for a one-year shore protection structure that would be removed in the summer of 1998 when the TTPR would be constructed. The only viable, low cost structure that could be installed before the onset of the winter storms was a quarrystone revetment placed along the toe of the bluff. This was called the "Storm Season 1997 Temporary Revetment" and consisted of a 4-5 stone cross section of armor stone (median weight 2,700 pounds) placed directly on Mirafi 1120N non-woven geotextile cloth. A one-foot deep trench was dug along the toe, and the filter cloth was placed from an elevation of approximately 4 feet above the toe to along the bottom of the trench, with the armor stones placed directly on the fabric. The stones will be reused in the TTPR when it is constructed in 1998.

Construction of the revetment was completed in October 1997

The structure was designed using relaxed design standards as the structure is only intended to prevent catastrophic bluff slope erosion from wave undercutting for the 1997/1998 storm season. It is anticipated that some of the stones could shift in response to the general lowering of the beach profile during the winter. Without this minimal structure, the survivability of the remaining bluff between the Great Highway and the beach was doubtful.

Monitoring and Emergency Response

Once the TTPR is in place and until the permanent shore protection solution is installed, cooperative management of the beach will be required between the City, NPS, and the CCC. The City is the principle organization responsible for taking action, and it is responsible for all costs incurred. Continued beach erosion in the unprotected areas north and south of the TTPR and maintenance in response to changes in the beach and TTPR itself, will require action by the City to maintain an effective erosion protection structure for the area between the two parking lots. Erosion will eventually damage or destroy the parking lots, but as mentioned earlier, would have to be catastrophic to extend to the Great Highway. The management of the beach south of Sloat Boulevard, therefore, has two primary objectives: (1) to monitor the 1920-foot reach and designate criteria for taking action to prevent undue damage to the parking lots or make the decision to let the parking lots go, and (2) monitor the TTPR and immediate areas for changes and take action based on those changes to preserve the shore protection's integrity.

At the time of this paper, a draft of Emergency Plan for Ocean Beach South of Sloat Boulevard has been under review by the City and eventually by the other concerned organizations. Implementation of the plan likely will not take place until after the TTPR is constructed.

This plan addresses responses by the City in coordination with other agencies for:

1. Preventing catastrophic erosion in the critical area between the two parking lots and for making repairs to the TTPR, including the installation of additional shore protection abutting the north and south ends of the TTPR.
2. Monitoring erosion in the reach south of Sloat Boulevard.
3. Installing temporary shore protection in areas outside the immediate area of concern for the TTPR until a permanent shoreline maintenance solution is implemented.

The emergency plan consists of the following sections:

Section 1.0 Introduction discusses the need for the plan and its objectives.
Section 2.0 Organizations and Responsibilities lists the organizations that will be

	responsible for monitoring and maintaining the temporary revetment and for participating in decisions on responses to further changes to the shoreline in the area of the revetment.
Section 3.0	Existing Beach Processes and Design Limitations summarizes the present conditions of the beach and the limitations of the temporary revetment design.
Section 4.0	Monitoring Inspections and Surveys describes the monitoring requirements including types of inspections and surveys, schedule and frequency of monitoring, and documentation requirements.
Section 5.0	Evaluating and Responding to Changed Conditions describes procedures for evaluating damage, presents potential damage scenarios that require action by the City, and defines procedures for responding to additional erosion of the bluffs.
Section 6.0	Recommendations for Sources of Material and Stockpiling presents potential sources for obtaining materials needed to repair or maintain the revetment and makes recommendations for stockpiling materials required for emergency repairs.

When the plan is finalized, probably in late 1998, it will form a basis for responding to changes along the beach and should expedite the decision making process when action must be taken. The plan will help ensure that CCSF can maintain the integrity of the TTPR in a timely manner, which will reduce greatly the cost of maintenance.

SUMMARY AND CONCLUSIONS

A temporary revetment was designed that would provide protection for City infrastructure that is threatened by localized erosion. Because of the potential impacts of further erosion, it was important for the City to get a revetment designed and constructed without undue delays.

All interested agencies were invited to participate from the start of the project to make sure that they understood the issues (including the risks of not building a revetment), to receive their comments and concerns early in the process, and to ensure the City would meet all agency requirements.

A permit was received from NPS for construction of the revetment. Permits from USACE and CCC were not required because the revetment is to be constructed outside of their jurisdictions.

The revetment is an interim measure that is intended to provide protection to limited areas of the shoreline that were considered to be at greatest risk until a more permanent solution can be implemented. Relaxed design criteria were used to allow the revetment to be constructed with the funds that the City had available.

Continued erosion is expected in the areas adjacent to the revetment that were not protected. Also, because of the relaxed design criteria, there is a higher risk of damage to the structure, especially if the beach in front of the revetment recedes at a greater rate than projected.

Because of the risks of continued erosion in the area, an important part of the project was the development of a monitoring and emergency response plan that will provide guidelines to the City for identifying and responding to further erosion in the area. The plan, which is currently being completed, will establish monitoring procedures, define damage or erosion levels that will warrant response by the City, and define procedures for response that have been agreed to by the City and NPS.

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COASTAL HAZARDS IN SOUTHERN CALIFORNIA: LOS ANGELES AND ORANGE COUNTY CITY RESPONSES

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ABSTRACT

This paper describes two surveys of southern California municipal planners to determine their degree of emphasis given to coastal hazards within their jurisdictions. With growing property losses associated with the coastal zones of southern California, the studies were undertaken to assess the role of scientific information and hazard responses in coastal planning for land use decisions. The findings show that while planners are gaining knowledge of their coastal zones, they still tend to view the coastal zone as just one element in the overall planning process. Their emphasis on day-to-day development permitting overshadows a proactive stance on strategic planning for coastal hazards.

INTRODUCTION

Coastal population growth with its concomitant development is a leading source of stress on the coastal environment (Coates, 1989). Nowhere is this force more apparent than in the southern California coastal zone with its increasing traffic congestion and lack of parking at local beaches, frequent sewage spills and beach closures, infilling and expansion of existing coastal developments, and continuing property losses from coastal erosion. A fifty year description of past and projected population growth shows the tremendous growth experienced by the California coastal zone; indeed, California has the largest total population in coastal counties in the United States (Warren, *et al.*, 1977).

Los Angeles and Orange Counties comprise more than 100 miles of the total 1100 mile California shoreline and account for the popular image of California scenic beach areas. These two counties also contribute the majority of coastal residents and have an intense infilling of their coastal zones. Coastal municipalities are inundated with new residents seeking housing, as well as tourists seeking places to stay. Older, smaller houses are replaced by mansions, condos and hotels. More residents and tourists demand more services and new businesses are opened to meet the need. Additional municipal services are required alike by residents, tourists and businesses.

Such growth impacts negatively on the environment, but the mere presence of this population and infrastructure bears impacts from the coastal zone as well. Coastal hazards are many in southern California. Winter storms along with torrential rains interacting with erosive soils have generated cliff slumping, mud slides and beach loss along with whatever structures were associated with these areas. For example, rains caused landslides, subsidence, and debris in Orange County resulting in a loss of homes, highway, railroad and municipal services for a total of $ 75 million (Walker and Berg, 1993). The City of Malibu suffered floods and mudslides from winter rains at an estimated coast of $ 22 million (Pool, 1995). The City of Redondo Beach was hit three times by winter storms in 1988, resulting in a loss of structures with 18 businesses destroyed and 400 jobs for a total of $ 32 million lost (Fischer, 1990). These costs do not include the costs of loss of business, litigation and additional protective works to mitigate future storm damage. California suffers an average of $ 10 million in property losses annually due to winter storms (Griggs, *et al.*, 1992).

Not only are there recurring hazards of high probability, such as winter storms, but hazards of lower probability also exist. These hazards include tsunamis, earthquakes and sea level rise. Given the loosely consolidated soils underlying coastal bluffs and comprising beaches in southern California, these hazards can be termed significant, especially in conjunction with winter storms. While tsunamis or earthquakes have not hit southern California's immediate coastal zone in historic times, the devastation recorded in tsunamis and quake events in Alaska was inmense (Brown, 1964). The recent quake in Kobe, Japan, with the epicenter in the coastal zone resulted in widespread loss of life, property and infrastructure (Reid, 1995).

Sea level rise is a "rising" hazard of immense scope. The expected national coastal property loss just in wetlands has been compared to the loss of the entire state of Massachusetts (Titus, 1991). While California losses are estimated to be less than elsewhere in the United States, such losses will be major and include impacts on the entire economy, the state's water resources, wetland habitats, fisheries, endangered species, coastal bluffs and beaches, and coastal properties (CED, 1989). San Francisco Bay would be irrevocably changed through the necessity of having to build seawalls and levees at an estimated cost of $1 billion with an annual maintenance of $100 million (Stein, 1990). Coastal beach retreat in southern California has been estimated to be between 30-200 feet by the year 2050 with an even greater risk inland from winter storms and wave run-up (Gustaitus, 1989).

With the southern California population attracted to coastal activities in spite of coastal hazards, a planning and regulatory framework was created to account for impacts of coastal use and development (CCA, 1988). The general policies of the California Coastal Act include:

1. Providing for maximum public access to and recreational use of the coast, consistent with private rights and environmental protection;
2. Protecting marine and land resources, including wetlands, rare and endangered habitat areas, environmentally sensitive areas, tidepools, and stream channels.
3. Maintaining productive coastal agricultural lands;
4. Directing new housing and other development to urbanized areas with adequate services rather than allowing a scattered, sprawling pattern of subdivision;

5. Protecting the scenic beauty of the coastal landscape, and
6. Locating any needed coastal energy and industrial facilities where they will have the least adverse impact.

It is of interest to note that coastal hazards do not appear as a general policy goal in the Coastal Act. The Act does not recognize coastal hazards; as only one section notes that developments shall, "minimize risk to life in areas of high geologic, flood and fire hazard" (section 30253). No coastal hazard requirements are set forth in either the Coastal Act or its implementing guidelines. Thus, local governments which must implement the California Coastal Act can be expected to have a wide variety of responses to coastal hazards.

Each coastal city is required to prepare and maintain a Local Coastal Program (LCP). The LCP incorporates the policies outlined in the Coastal Act and must be approved by the California Coastal Commission. A LCP is the city's specific, long-term coastal management plan which includes a land use plan, zoning ordinances and other implementing actions. LCP's are drafted by coastal cities, submitted to the Coastal Commission for approval and, upon approval, are formally adopted by the City Council of the authorizing city (CCC, 1981).

Because municipal governments bear the brunt of coastal planning for environmental and hazard impacts, this paper focuses on this level of government. The objective is to identify the extent to which coastal municipalities in southern California plan for coastal hazards and what mitigation measures, if any, are used or being considered. A further objective is to assess the extent of knowledge city officials have concerning coastal problems, resources and hazards, and what features are incorporated, if any, into their LCP.

SELECTED PREVIOUS STUDIES

In recent case studies about California coastal cities are scant because most studies are conducted statewide. One such state-sponsored study focused on the coastal policies of local governments in the Los Angeles area before and after the passage of the California Coastal Act of 1976 (Warren, 1977). The study looked at development patterns and the permit processes to obtain permission to develop coastal land. For example, before the Coastal Act, Redondo Beach allowed extensive coastal development which transformed the City from a small, "local only" beach community to a larger municipality with King Harbor and an urban redevelopment project. After passage of the Coastal Act, the new permit process halted many proposed projects in Redondo Beach, including some projects with tremendous citizen support. The author of this study concluded that the Coastal Commission cannot make decisions that are universal, but rather should take time to review local government policies which reflect the historical patterns and preferences of local citizenry.

Research focusing on coastal hazards based on surveys of municipal planners are growing in number. One of the earliest efforts was on the response of coastal municipalities to coastal flood hazards (Burton, *et al.*, 1969). This research reported on the adaptions municipalities were making to coastal storm experiences in order to reduce the associated losses of life, property and local revenues. The study area covered the eastern U.S. coast from Maine through North Carolina from which 15 municipalities were selected for case studies. A major finding was that land use zoning is best left to local government, since their regulations of land use recognize flood hazard planning on the basis of the degree of hazard faced in each location. In this way, the type of use and construction can be adjusted to fit the degree of hazard involved.

A survey of all coastal counties in Florida having a sandy beachfront focused on local officials' perceptions and responses to shoreline erosion (Fischer, *et al.*, 1986). Detailed questionnaires sought information on local coastal objectives, physical beach trends, beachfront land uses and planning, erosion control measures favored, and coastal issues encountered in beach management. Results showed coastal county officials were on the whole responding to beach erosion and developing measures for reducing dune and beach loss via their general plans. In addition, the economic and policy issues associated with shoreline erosion were enumerated (Fischer, 1990).

One study tracked the "American Trader" oil spill in Huntington Beach (Fischer and Martinet, 1993). The problem which surfaced during this accident was the lack of coordination between local governments that were affected by the spill. There was little communication among the 5 immediately affected cities and the 49 other federal, state and local agencies involved in the clean-up efforts. This study stressed the importance of taking a proactive approach of planning for contingencies.

Two other studies concerning coastal hazards focused on increased coastal erosion resulting from sea level rise. The first study, conducted in Ocean Beach, California, near San Francisco, stated that by the year 2100, sea level rise will provoke a tremendous amount of erosion (Wilcoxen, 1986). In Ocean Beach, a Sewer Transport Project located in the coastal zone was approved by the California Coastal Commission and the participating cities without full knowledge of the effects of sea level rise on the project. This study showed that erosion caused by sea level would undermine the approved sewer transport project. The second study on sea level rise focused on planning for this hazard. The author states that, "planning for global (warming) is made difficult not only as a result of the diversity of agencies involved in producing country assessments and/or recommendations of actions, but also because such assessments have been undertaken in an uncoordinated manner, as a crisis response to current concerns, and without clear definition of spatial and temporal boundaries" (Pernetta and Elder, 1992). This study concluded that many, "local, regional and national studies have failed to define precisely the changed conditions or the time frame under which projected scenarios will occur and have often been based on general rather theoretical reviews of broad areas of impact which may or may not occur in any given location" (ibid).

The Santa Monica Bay Restoration Project (SMBRP, 1994), a non-profit organization, developed a plan in 1994 for restoring Santa Monica Bay to a more pristine condition. This plan takes into account the stressors put on the Bay from the amount of growth and development in the Los Angeles County area. In an interview with Marianne Yamaguchi, Senior Planning Manager at SMBRP, she stated that beach erosion was not accounted for in the restoration plan. The plan examined the pollution factors and the natural resources of the Bay for developing a comprehensive plan for restoring the Bay. She indicated that while beach erosion was an issue for the Bay, information was not readily available.

The U.S. Corps of Engineers developed a five year study on the state of the Orange County coast (COE, 1992). The purpose of this study was to develop a data base for improving planning design and better management of this coastal zone. The study is a comprehensive effort geared toward the assessment, evaluation and analysis of the coastal processes which prevail along the southern California coastline.

Two surveys of local government responses to coastal hazard were recently completed. The first concentrated on California municipal efforts to develop and protect their coastal zones via municipal ordinances and regulations (Griggs, *et al.*, 1992). This study relied on a questionnaire and interviews on the use of setback standards, technical study requirements, regulation of seawalls, and desired changes from state agencies. The second study used a telephone survey to determine Louisiana coastal residents and local officials' views on the impact of sea level rise (Lascha and Emmer, 1992). The California and Louisiana surveys showed the need for clearer policies from state governments to assist local land use planning in potentially hazardous coastal areas. Coastal hazard information was deemed lacking as well as the regulatory measures needed to reduce development in threatened areas. Surprisingly, only 4 out of the 48 California local governments surveyed had a specific ordinance dealing with geologic hazards. Even though the Louisiana study dealt with sea level rise and the California study dealt with coastal erosion and flooding, both studies showed that local officials felt they lacked the regulatory measures to address the problems they faced. While no official wanted to restrict development in response to coastal hazard, local governments seemed increasingly aware of the conflicts they faced between public and private concerns.

A survey study involving the authors was conducted among northern Spanish coastal municipalities. It showed that local officials tend to rely on personal observations, legal requirements and tourist demands for making coastal land use decisions (Fischer, *et al.*, 1995). Scientific information in the form of expert studies had not played a role in decision-making. The views of these officials with respect to the need for coastal protection and hazard avoidance were at variance with scientific studies of the same region.

These three survey studies, California, Louisiana and Cantabria, show that coastal municipalities desire clearer policies and regulatory measures from the next higher level of government to assist them in planning for coastal protection and hazard avoidance. As well, a gap seems to exist between what is known among scientists and what is being implemented locally by municipalities (Rivas, *et al.*, 1994).

METHODOLOGY

The data for this study was obtained through two surveys administered by three research assistants, once in 1995 and once in 1997 with a more restricted focus on erosion. In Los Angeles Country, the cities of Malibu, Santa Monica, Rancho Palos Verdes, Manhattan Beach and Redondo Beach were contacted. In Orange County, the cities of Seal Beach, Huntington Beach, Newport Beach, Dana Point and San Clemente were contacted. The two large cities of Long Beach and Los Angeles were excluded because of their size relative to all other coastal cities and their breakwater protected shoreline. Table 1 describes these municipalities.

Table 1 Selected Southern California Municipalities

MUNICIPALITY	POPULATION	COASTAL POPULATION	COASTAL LENGTH (MILES)	PERSONS PER COASTAL MILE
MALIBU	11,500	8,000	27.00	296
SANTA MONICA	89,902	10,000	3.50	2857
MANHATTAN BEACH	33,000	8,000	2.10	3809
REDONDO BEACH	60,500	15,000	2.75	5454
RANCHO PALOS VERDES	41,000	6,000	7.50	800
SEAL BEACH	26,000	10,000	2.00	5000
HUNTINGTON BEACH	181,000	25,000	8.00	3125
NEWPORT BEACH	70,000	40,000	9.00	4444
DANA POINT	34,000	28,000	8.00	3500
SAN CLEMENTE	41,000	23,500	3.50	6714
TOTAL	**588,002**	**173,500**	**73.35**	**2378**

Of the cities surveyed, approximately 30% of their population lives within one mile of the shoreline along the southern California coast. The population density within one mile of the shoreline and for each mile along the coast is shown in Table 1.

It is recognized that coastal planning can be influenced by the national, regional and local levels of government as well as non-government organizations and the general public. However, this study focused on local government because is in this central arena where coastal plans are forged, interpreted and implemented. Local government officials integrate the requirements of other government levels with demands from their constituents to create the plans that shape the development of their respective coastal zones. Therefore, this study was directed solely to local governments of small- to medium-sized cities in the two county region.

An advance copy of the questions was sent to the planning director of each municipality included in the study. Along with the questions a cover letter was enclosed to request that the questions be given to the municipal planner with responsibility for technical coastal considerations prior to the interview. Each respondent was asked each of the pre-determined, multiple-option questions in the order presented in the questionnaire and their responses were recorded by the interviewer.

The questions asked of these local officials included what coastal problems were being experienced, what coastal features were protected, what coastal hazards were acknowledged, their knowledge of sea level rise, planning response to conflicts involving coastal protection and development, and their preferences for coastal scientific information. The questions were drawn from the California, Louisiana and Spanish studies previously described.

Since the focus of the study was on describing the degree of coastal-centered planning done by the municipalities, the data from the questions were subjected to a qualitative analysis. For each question the number of municipalities responding to that element were counted, totaled and placed into a table that grouped similar questions and responses. Because the number of municipalities in the study universe was only 10, no summaries of the data were made.

SURVEY RESULTS AND DISCUSSION

Table 2 shows the coastal zone problems being experienced by each of the municipalities. In 1995, 6 cities reported problems with cliff slumping and 4 noted coastal erosion, while in 1997, erosion jumped to 7 out of the 10 cities and cliff slumping went from 6 to 5 cities. Other than the addition of the three cities noting erosion problems (a rise of 57%) in 1997, the types of coastal problems varied only by one city between 1995 and 1997.

Table II. Coastal Problems Experienced in Ten Cities in Southern California.

Coastal Problems Experienced	**Erosion**		**Cliff Slumping**		**Flooding**		**Channel Silting**		**Increasing Urbaniz.**	
	1995	1997	1995	1997	1995	1997	1995	1997	1995	1997
Malibu		X			X		X			
Santa Monica		X	X	X					X	
Manhattan Beach								X	X	
Redondo Beach						X		X		
Rancho Palos Verdes	X		X	X						
Seal Beach	X	X				X				X
Huntington Beach		X	X	X		X				
Newport Beach	X	X	X		X					
Dana Point		X	X	X						
San Clemente	X	X	X	X						
TOTAL	**4**	**7**	**6**	**5**	**2**	**3**	**1**	**2**	**2**	**1**

Table 3 shows the reasons cited by the municipalities for their coastal problems. Municipalities viewed urbanization pressures, nature and lack of funding as the reasons

Table III. Reasons for Coastal Problems in Ten Cities in Southern California.

	Incr. Urbaniz.		**Nature**		**Lack of Local Authority**		**Lack of Funding**	
Reasons for Coastal Problems	1995	1997	1995	1997	1995	1997	1995	1997
Malibu		X	X				X	X
Santa Monica	X		X	X				
Manhattan Beach	X	X		X		X		X
Redondo Beach		X		X		X		X
Rancho Palos Verdes	X			X	X		X	
Seal Beach	X	X		X		X	X	X
Huntington Beach				X				X
Newport Beach	X	X	X					X
Dana Point		X						X
San Clemente				X			X	X
TOTAL	**5**	**6**	**3**	**7**	**1**	**3**	**4**	**8**

behind their coastal problems. The dramatic change between 1995 and 1997, was the increase in the number of cities noting nature and lack of funding as reasons for their coastal problems. A lack of funding would likely discourage cities from designating beach erosion and cliff slumping as fiscal priority items because in times of financial hardship voters tend to favor basic city services. Nature as a reason could have come from the increased media coverage of "El Niño" expectations as well as the need to build a base to capture increased funding.

Table 4 shows the specific types of natural coastal features protected by each municipality. The table indicates that a majority of the municipalities actively protect beaches and open spaces while few cities protect dunes, farms and rivers. The table also indicates the measures employed by municipalities to protect these natural features. Frequently-used protection measures include regulations, buffer zones, special use plans/ zones, building codes and engineering structures. No municipalities reported buying-out owners as a coastal protection measure. As shown in Table 3, this may be due to lack of funding for local coastal cities. Few municipalities reported banning activities or providing tax incentives as coastal protection methods.

Table IV. Parts of Coastal Zone Legally Protected by Municipalities.

	NATURAL FEATURES PROTECTED													
MUNICIPALITY	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**M**	**N**	**O**
Malibu													X	
Santa Monica													X	
Rancho Palos Verdes		X		X	X		X		X			X		X
Manhattan Beach		X							X					
Redondo Beach													X	
Seal Beach		X	X		X						X	X		
Huntington Beach	X	X	X	X	X	X	X	X	X	X	X	X		
Newport Beach	X	X	X		X		X				X	X		X
Dana Point		X	X	X			X		X	X		X		
San Clemente		X		X	X		X	X	X			X		
Total Number	**2**	**7**	**4**	**4**	**5**	**1**	**5**	**2**	**5**	**2**	**3**	**6**	**3**	**2**

A: dunes B: beaches C: wetlands D: cliff tops E: fauna F: farms
G: open spaces H: old buildings I: hazardous areas J: rivers K: bays M: vegetation
N: no responses O: Other

The characteristics which make up coastal development for the cities in this study are shown in Table 5: 100% have housing, 90% have piers, commercial property/ businesses and parking facilities, and 60% have tourist facilities. All of the cities surveyed have housing located within the coastal zone which corresponds to the amount of population located along the coast. The property value in Orange County is estimated at over $150 billion, with ocean front property carrying the highest assessment. Only the City of San Clemente (as part of its General Plan) reports the availability of a substantial amount of land for development within its coastal zone.

Table V. Existing Coastal Development (1997)

Municipality	Pier	Marina	Tourist Facilities	Housing	Commercial	Parking	City Services	Other	Total
Malibu	X			X					2
Santa Monica	X		X	X	X	X	X		6
Manhattan Beach	X			X	X	X			4
Redondo Beach	X	X	X	X	X	X		X	7
R. Palos Verdes			X	X	X	X	X	X	6
Seal Beach	X		X	X	X	X	X		6
Hunt. Beach	X		X	X	X	X		X	6
Newport Beach	X	X		X	X	X			5
Dana Point	X	X		X	X	X		X	6
San Clemente	X		X	X	X	X	X	X	7
TOTAL	9	3	6	10	9	9	4	5	55

OTHER: Electric Plant, Churches, agriculture, interpretive center, recreation, county parks, railroad station

The commercial business base in the coastal zone provides vital services to the local population, but more importantly to the tourists. Tourism is vital to the southern California economy contributing $7.1 million directly to Los Angeles County in 1991 (SMBRP, 1994). The parking facilities support the huge resident population as well as visitors to the coastal area.

These structures become threatened when there is a loss of beach protecting the coast. This is evidenced by losses from the 1982 and 1983 storms, amounting to $40.1 million in damages (COE, 1992). From the 1988 storms there was a total of $ 32 million in damages, especially King Harbor in Redondo Beach. Seal Beach reported flooding of homes in both 1983 and 1988 because of the loss of beach width protection. Piers have been rebuilt as a result of the damage from these storms such as in Redondo Beach, Manhattan Beach, Seal Beach, Malibu and Huntington Beach.

Table 6 show approximately 90 miles of shoreline affected by exposure to the ocean. The percentage of shoreline types is as follows: 66% is beach, 22% is cliff, 6% is wetland, and 6% is harbor. The coast of southern California is predominantly sandy beach exposed to erosion. Erosion of cliffs, rounded and vertical, is apparent when there is no vegetation to hold the soil. Harbors accumulate eroded sands due to the longshore current. Wetlands usually are protected by the beach, however, they experience the effects of erosion through the absence of sediment from the riverways.

Table VI. Type of Shoreline (miles).

MUNICIPALITY	CLIFF	BEACH	WETLAND	HARBOR	TOTALS
MALIBU	10.00	27.0	1.00		**38.00**
SANTA MONICA	0.40	3.50			**3.90**
MANHATTAN BEACH		2.10			**2.10**
REDONDO BEACH	0.25	1.75		1.00	**3.00**
R. PALOS VERDES	5.10	2.25			**7.35**
SEAL BEACH		2.00			**2.00**
HUNT. BEACH		8.00	4.00		**12.00**
NEWPORT BEACH		5.50		3.50	**9.00**
DANA POINT	1.00	6.00		1.00	**8.00**
SAN CLEMENTE	3.00	0.50			**3.50**
TOTAL	**19.75**	**58.60**	**5.00**	**5.50**	**88.85***

* Some beach areas backed by cliff, wetland or harbor creating an overlap.

Table 7 shows the coastal hazards officially recognized in Local Coastal Plans. Beach erosion and pollution stand out as the hazard most frequently recognized, followed by

Table VII. Hazards Officially Recognized by Ten Municipalities

MUNICIPALITY	S	F	CS	LM	BE	SL	T	W	WF	P	AS	E	O	N	NP
Malibu															X
Santa Monica															X
Rancho Palos Verdes	X	X	X	X	X		X		X	X			X		
Manhattan Beach										X	X				
Redondo Beach	X	X			X	X	X	X		X					
Seal Beach	X	X			X						X		X		
Huntington Beach	X	X	X	X	X	X	X	X	X	X	X	X			
Newpot Beach	X	X	X	X	X		X		X	X	X	X	X		
Dana Point	X	X	X	X	X	X	X		X	X	X				
San Clemente			X		X					X					
Total Number	6	6	5	4	7	3	5	2	4	7	5	2	3	0	2

S: storms
SL: sea level raise
AS: accidental spills
F: floods
T: tsunamis
E: explosion
CS. cliff slumping
W: winds
O: Others
LM: landslides/mudflows
WF: wildfires
N: none
BE beach erosion
P pollution
NP. no response

storms and floods. No city ignored coastal hazards, although two cities did not respond to this question.

The cities surveyed have reported the following safeguards for shoreline protection purposes (Table 8): 60% use groins, 30% use breakwaters; 20% use jetties, 20% use riprap; and 10% use seawalls. These structures are built to prevent movement of sediment away from or into an area, improving navigation of harbors, flood relief, and protection of property from storm waves. In Newport Beach there are eight groins protecting the coast causing the shoreline to be irregular and inhibiting the movement of longshore sediment. South of these groins fields, Laguna, Dana Point and San Clemente suffer the loss of beach width. Jetties at Alamitos Bay and Anaheim Bay eliminate sand transport to Surfside, Sunset and Huntington Beach. The Huntington Beach Pier acts as a permeable groin reducing longshore current and slowing the travel of sediment. In Malibu riprap protecting housing structures has diminished the amount of sediment down shore. In Santa Monica the 2,000 foot breakwater has deteriorated from the 1982-1983 storms causing the beaches to become narrower. However, the sand is no longer trapped allowing sand to replenish beaches to the south (ibid).

Table VIII Existing Shoreline Protection (1997)

MUNICIPALITY	Groins	Jetties	Riprap	Breakwater	Seawalls	TOTAL
MALIBU	X		X		X	3
SANTA MONICA	X			X g		2
MANHATTAN BEACH	X a					1
REDONDO BEACH	X b					1
R. PALOS VERDES						0
SEAL BEACH	X c	X d		X		3
HUNT. BEACH	X a					1
NEWPORT BEACH		X e				1
DANA POINT				X h		1
SAN CLEMENTE			X f			1
TOTAL	6	2	2	3	1	14

* Some beach areas backed by cliff, wetland or harbor creating an overlap

a= Pier b= 2 (0 75, 0 20 mi) c = 1200 ft d = 2 (1600 2500 ft) e = 8 (COE) f = 1 5 mi

g= 2000 ft h= 2 (1 1.0 25 mi)

According to Table 9, the cities have observed erosion as follows: one city has much erosion, 70% have some erosion, and 20% no loss of shoreline due to erosion. In Malibu Las Tunas Beach has experienced significant erosion creating an unstable beach face. In Los Angeles County over the last 16 years there have been about three million cubic yards of sand placed on beaches. In 1968 the Army Corps of Engineers engaged in a sand replenishment program in Redondo Beach which makes up most of that beach today. Santa Monica has experienced a loss of beach width resulting from the deterioration of a breakwater.

Table IX.- Loss of Shoreline due to Erosion (Perceived, 1997)

MUNICIPALITY	**MUCH**	**SOME**	**NONE**
MALIBU		X	
SANTA MONICA		X	
MANHATTAN BEACH			X
REDONDO BEACH			X
R. PALOS VERDES		X	
SEAL BEACH		X	
HUNT. BEACH		X	
NEWPORT BEACH	X		
DANA POINT		X	
SAN CLEMENTE		X	
TOTAL	**1**	**7**	**2**

In Orange County, Seal Beach, Sunset, Surfside, Newport Beach, Dana Point (Doheny State Beach) and San Clemente have experienced loss of beach width from erosion. Every five to six years, 1-2 million cubic yards of sand is placed on beaches in Newport Beach from an offshore dredging program. In 1983-84 approximately 250,000 million cubic yards of sand were used to replenish Seal Beach from the Naval Weapons Station (ibid). Seal Beach has reported a loss of 6000 cubic/yards and recently trucked in 15,000 cubic yards of sand to replenish sand lost. This loss is important for navigational purposes due to oil tanker traffic and a recent grounding there. All the area's beaches conduct a seasonal shift in positioning of lifeguard towers.

The replenishment programs cited are important because they reflect significant erosion and the inability of the respective beaches to replenish naturally. According to the planners interviewed, the losses of beach width are primarily due to the result of sediment loss from channelization and flood control measures to protect inland areas from flooding. However, the shoreline "protection" measures contribute to this loss as well.

Cliffsides also have been experiencing a degree of noticeable erosion. In Rancho Palos Verdes, the U.S. Coast Guard Point Vicente Lighthouse has been moved once to avoid its loss from the eroding cliff. In Huntington Beach there has been loss of cliff due to erosion, and Santa Monica, Dana Point and San Clemente also have experienced cliff loss.

The responses in Table 10 reflect the opinion that coastal development does cause degeneration (erosion) of the shoreline. The responses were as follows: 10% strongly agreed, 50% agreed, 20% disagreed, none strongly disagreed, and 20% had no opinion.

Table X. Development Caused Degeneration of the Shoreline (1997)

MUNICIPALITY	Strongly Agree	Agree	No Opinion	Disagree	Strongly Disagree
MALIBU		X			
SANTA MONICA		X			
MANHATTAN BEACH		X			
REDONDO BEACH		X			
R. PALOS VERDES				X	
SEAL BEACH	X				
HUNT. BEACH				X	
NEWPORT BEACH		X			
DANA POINT			X		
SAN CLEMENTE			X		
TOTAL	1	5	2	2	0

These observations were obtained from local planners, and Larry Paul from Orange County, Beaches and Harbors, and Gregory Woodell of Los Angeles County, Beaches and Harbors, reaffirmed these observations. They further emphasized how the channelization of the riverways for the purposes of flood control has significantly contributed to the erosion process. This channelization is a direct result of the enormous population found in southern California and the amount of land pressure due to the population density in a relatively small area. This pressure has resulted in expansion of public infrastructure, flood control and other measures to adapt to such a population concentration. Sand delivery has been reduced in the Los Angeles, San Gabriel and Santa Ana Rivers as a result of sediment impoundment behind dams and greatly changed land uses. Urbanization has brought a reduction in sediment as erodible surfaces are landscaped.

The flood control measures impede sediment upstream, thus preventing materials from reaching the ocean for the remainder of the year due to the long dry season. The beach lost during the winter months is not replaced leaving the shoreline vulnerable without the ability to naturally replenish itself. Also, shoreline protection measures contribute to the reduction of longshore sediment, as previously discussed. The loss of beach has reduced recreational area and structure protection in this coastal zone, risking further damage from storms.

Table XI. Municipal Preferences for New Coastal Zone Projects and Planning Measures

IF HAD $ 25 MILL DOLLAR/ IF HAD TO MATCH BY 50%

MUNICIPALITY	RC	NP	P	MA	PC	HM	RP	M	ST	WP	ES	O	N	P	YM	NM
Malibu						X	X			X						X
Santa Monica			X				X					X			X	
R. Palos Verdes						X					X					X
Manhattan Beach		X	X				X									X
Redondo Beach				X		X										X
Seal Beach											X	X				X
Huntington Beach		X		X						X	X				X	
Newport Beach												X			X	
Dana Point			X	X	X										X	
San Clemente		X			X										X	
Total Number	0	3	3	3	2	3	3	0	0	2	3	3	0	0	5	5

- *If Had $25 Mill Dollars:* RC = New roads to coast, NP = New parking lots on coast, P = Vew parks in city, MA = Museum/aquarium, PC= Promenade along coast, HM = Hazard mitigation on coast, RP = Recreational pier, M= Public marina on coast, ST= Enhanced sewage treatment, WP= Wetland protection, ES= Engineering structures, O= Other, N= None, P= No response
- *If Had to Match by 50%* YM= Yes-would match funding by 50%, NM= No-would not match funding by 50%

Table 11 shows preferences for new projects in the coastal zone and is based on the hypothetical question of how each municipality would spend $25 million dollars. Coastal and non-coastal choices were included in the list of spending alternatives. Interestingly, there was little agreement among the municipalities about the most desirable new projects. Preferences were for hazard mitigation and new parks followed by new parking lots, a museum or aquarium, a recreational pier and engineering structures. No municipalities favored new roads to the coast, a new public marina or enhanced sewage treatment. Most municipalities would recommend the same expenditures if their municipality had to provide 50% of the matching funds for the new projects, particularly for hazard mitigation. Orange County cities appear more willing to provide matching funds than Los Angeles County cities.

Table 12 describes the types of hazard studies used to assess and mitigate those hazards. Most municipalities identified storm and beach erosion hazards, but interestingly, the majority of municipalities reported using urban planning as a means of hazard assessment and mitigation. Urban planning cannot solve the problems that arise from beach erosion and storms, but engineering studies, equally used, are more useful for this type of problem. Santa Monica is the only municipality that uses the types of studies identified in the survey to assess and mitigate identified coastal hazards.

Table XII. Types of Natural and Technological Hazards Studies Undertaken

MUNICIPALITY	E	G	UP	VA	SE	O	N	P
Malibu								X
Santa Monica	X	X	X	X	X			
R. Palos Verdes			X		X			
Manhattan Beach						X		
Redondo Beach	X		X					
Seal Beach	X							
Huntington Beach					X			
Newport Beach	X	X	X					
Dana Point	X	X	X					
San Clemente	X	X	X		X			
Total Number	**6**	**4**	**6**	**1**	**4**	**1**	**0**	**1**

Hazards Studies Undertaken: E = Engineering, G = Geological, UP = Urban Planning, VA = Vegetation assessment, SE = Socio-economic, O = Other, N = None, P = No response

Table 13 illustrates the measures used by municipalities to avoid coastal hazards.

Table XIII. Types of Measures Used to Avoid Coastal Hazards.

MUNICIPALITY	BA	PS	BC	EP	RL	BO	DH	ES	HI	EP	LU	BZ	O	N	P
Malibu															X
Santa Monica	X	X	X	X	X	X	X	X	X	X	X	X			
R. Palos Verdes			X				X				X	X			
Manhattan Beach													X		
Redondo Beach			X					X			X				
Seal Beach			X	X				X	X	X	X		X		
Huntington Beach			X				X	X			X				
Newport Beach			X				X	X		X	X	X			
Dana Point		X		X				X		X	X	X			
San Clemente	X	X	X				X			X	X	X			
Total Number	2	3	7	3	1	1	5	6	2	5	8	5	2	0	1

Measures Used to Avoid Hazard

BA = Ban Activity, PS = Performance Standards, BC = Building Code, EP = Educational Program, RL = Reimbursement for Loss, BO = Buy-out Owner(s), DH = Designation of Hazard Zones, ES = Engineering Structures HI = Require Hazard Insurance, EP = Evacuation Plan, LU = Land Use Planning, BZ = Buffer Zone, O = Other, N = None, P = No Response

Again, Santa Monica used all studies/measures noted in the survey. Most of the municipalities use land-use planning measures because of the California Coastal Commission mandate requiring municipalities to include a Land Use Element in their LCP. The City of Malibu is the only survey municipality that does not have a LCP and could not respond to this section of the survey.

Table 14 describes hazard avoidance measures that municipalities are willing to adopt. Most of the municipalities were willing to engage in erosion setback and land-use planning based on hazard potential and post storm/flood reconstruction restrictions. A lesser number of cities would use educational programs, remodel infrastructure, create special hazard study zones and require hazard insurance of residents in the coastal zone. Not one municipality was willing to pay part of the cost of residents to relocate or purchase hazardous areas as hazard avoidance measures. These results are similar to a survey of coastal municipalities done in North Carolina (Godschalk, *et al.*, 1989).

Tabla XIV. Types of Measures Willing to Consider to Avoid Hazards.

MUNICIPALITY	ES	EP	LU	RI	PR	BZ	SL	DR	DS	BS	DB	RI	CR	HZ	BH	RI	BN	O	P
Malibu	X		X		X	X								X		X	X		
Santa Monica	X	X	X		X	X	X		X			X		X		X			
R. Palos Verdes	X			X						X		X		X					
Manhattan Beach		X										X							
Redondo Beach											X								
Seal Beach			X		X					X							X		
Huntington Beach		X	X		X											X			
Newport Beach																		X	
Dana Point	X	X	X	X	X					X	X	X		X		X	X		
San Clemente	X									X	X								
Total Number	5	4	5	2	5	2	1	0	1	4	3	4	0	4	0	4	3	1	0

Measures to Consider:
ES = Erosion Setback, EP = Educational Program, LU = Land-use Planning based on Hazard Potential , RI = Remodel Infrastructure, PR = Post Storm/Flood Reconstruction Restrictions, BZ = Buffer Zone around Hazardous Areas, SL = Stop Leasing Public Land, DR = Dune Revegetation, DS = Destroy sea walls/groins, BS = Build sea walls/groins . DB = Development Plan , RI = Restrict New Public Infrastructure, CR = Pay Part of Costs to Relocate, HZ = Create Special Hazard Study Zones, BH = Buy Hazardous Lots, RI = Require Hazard Insurance, BN = Beach Nourishment, O = Other, P = No response

Finally, Table 15 shows that sea level rise impacts are expected by local planners. Loss of beaches and housing are the effects most expected from the heightened flooding associated with sea level rise. No city planners were unaware of this pending, long-term hazard.

Table XV. Expected Sea Level Rise to Affect Areas in Municipalities.

MUNICIPALITY	NE	F	LB	NB	FW	SC	LI	LH	DK	O
Malibu		X	X	X	X	X		X		
Santa Monica		X	X	X		X		X		
Rancho Palos Verdes		X	X			X	X	X		X
Manhattan Beach			X							X
Redondo Beach		X	X							
Seal Beach		X	X	X	X		X	X		
Huntington Beach		X	X	X	X	X		X		
Newpot Beach		X	X	X	X		X	X		
Dana Point	X									
San Clemente			X			X	X	X		X
Total Number	1	7	9	5	4	5	4	7	0	3

NE no effect
F flooding of inhabited areas
LB loss of beaches
NB narrowing of beaches
FW flooding of wetlands
SC slumping of cliffs
LI loss of infrastrucure
LH loss of housing
DK don't know
O Other

CONCLUSION

The results of this study confirm that local planners increasingly are aware of existing and potential coastal hazards in their municipalities and are exploring these issues in accordance with prescribed mandates and their own perceptions of the magnitude of these problems in relationship to other city issues. One problem that is not unique to the surveyed coastal municipalities is the inherent difficulty in dealing with coastal zone issues separately from non-coastal zone issues. Although many coastal problems really need special use review and planning, the magnitude of the coastal planning equation in relation to the entire municipal planning process is often lost or denied. Although only one survey municipality, Manhattan Beach, reported employing a planner dedicated to coastal issues; most cities reported that all of their planners deal with coastal issues. Perhaps this lack of specialization illustrates the municipal perspective on coastal zone issues as being just part of the usual mix of planning issues in general. However, each municipality with a coastal zone is responsible for a unique natural resource/hazard area.

Some coastal problems may not receive proactive attention because of the lack of coastal information. No surveyed municipality indicated that it would be willing to seek expert advice about coastal issues. This may be based on the assumption that expert advice must be purchased and coastal issues are not considered a priority in this era of downsizing and continuing lack of funding. Municipalities could, however, have access to experts conducting scientific research on coastal problems whose findings could assist them in identifying and mitigating potential coastal hazards. Often such research is conducted by local universities and is free to those interested in the information.

Given the unique planning and mitigation issues associated with the coastal zone, the lack of information about the zone and the municipal fiscal scarcity hampering the creation of such valuable information, perhaps it should be recognized that the coastal zone has a very special, untapped resource at its disposal... its wealthier-than-average residents. Coastal municipalities in southern California generally have a large population of upper and upper-middle class residents. As an example, few surveyed municipalities were willing to require hazard insurance or consider the leasing of public lands. Such revenue streams could help pay for coastal hazard identification and mitigation as well as fund other coastline preservation activities. The concept of having hazard zone residents bear the cost of living in that hazard zone is not new, but must be revisited as the era of sea level rise looms. This new era is characterized by a new understanding and acceptance of the unique short and long term issues and remedies associated with the coastal zone and the real costs of inhabiting, maintaining and preserving this unique area.

Although the California Coastal Commission works with local governments to protect the coastal zone, they do not appear to help local governments prepare for future, long term hazard. The Coastal Commission is largely responsible for the permit process in the coastal zone by granting and denying developers the right to build on certain coastal properties, even though it lacks local knowledge of municipal preferences. This permit process has become the focus of energy for the state and local coastal municipalities rather than a larger picture of identification and mitigation of natural and man-made coastal hazards.

Currently, governance of coastal hazards is administrated reactively, ultimately costing more and achieving less per dollar expended than if a proactive governance approach were used in the coastal zone. Generally, the region's storm damage was far more expensive than the mitigation measures that could have prevented or minimized storm damage. A shift in the perception of coastal zone governing bodies would be important, especially moving the primary focus away from individual development and shoreline protection projects and toward coastal zone management.

It is evident from the general results of this survey that not nearly enough is being done to protect the southern California coastline by the municipalities. Survey results indicate that coastal municipalities are taking inconsistent approaches to local coastal planning and protection. Municipalities should redirect their efforts toward greater coastal hazard identification and mitigation. Local governments must be empowered to identify coastal problems and mitigation strategies and work in concert with the California Coastal Commission to review those strategies from a regional perspective. The small, minor, more local, coastal development issues should be left solely to the municipalities. This shift in governance and perspective, when combined with financial and legislative support for coastal hazard planning, would provide a true foundation for cost-effective, long term, coordinated coastal zone management.

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ON THE EDGE

Robbed by Dams, Scoured by Seawalls, Devoured by Winter Storms, Ventura County May Soon Lose One of Its Most Precious Resources

Paul Jenkin

Edited by
Jim Little

as published in The Ventura County Reporter, Sept 18, 1997

Take a moment out from the California Beach Festival to stroll westward toward Surfers' Point. As you approach the mouth of the Ventura River, cast an appraising eye. You may wonder where the rubble, concrete barricades, and rusting chain-link fences came from and where portions of the bike path have gone.

At low tide, keen-eyed observers might spot the corroded automobile chassis with wood-spoked wheels that lies in the surf zone. Its curious presence marks decades-long efforts to stabilize the shoreline with everything from a demolished concrete bath house built near Surfer's Point in the 1920s to a tombstone that once marked the final resting place of someone at Cemetery Park on Poli Street.

This small, but important stretch of Ventura's shoreline is one of the most obvious examples of coastal erosion in the county. Living testimony to the folly of building too close to the sea, it speaks loudly to ineffectual attempts to protect such development.

Coastal tourism is California's largest ocean-dependent industry. It brought in an estimated $45 million dollars to Ventura County in 1992, according to "California's Ocean Resources: an Agenda for the Future," which was authored by the governor's office and released in March 1997. Visitors and residents spent $4.1 million on coastal recreation, which the report says is enjoyed by 70% of those who live in the Golden State.

Along with providing a wonderful place to stroll, soak rays, and throw a frisbee for the dog, the beach serves as the shore's first line of defense against the relentless forces of the ocean. But this buffer is disappearing, and man is speeding its demise.

More than 86% of California's 1,100-mile coastline experiences erosion at an adverage statewide rate of about one foot per year. On undeveloped shores the sand is free to come and go, cliffs collapse, and dunes are breached during times of high tides and surf. On developed coastlines, man frequently intercedes.

Hard Solutions, Hard Consequences

Because of erosion, developments that were originally built a comfortable distance from the ocean, today are finding themselves perched precariously on the edge. In years past, "hard" structures were erected to protect them. The seawalls on the Ventura Promenade and at Faria Beach, and rock revetments that line the freeway and Old Coast Highway north of Ventura are good examples.

While protecting the structures they front, such coastal armor is now known to alter the natural flow of sand, thereby destroying downshore stretches of beach. At Faria, yesterday's beachfront home is today's oceanfront property.

Ventura beaches get their sand from up-coast and inland sources; rivers, creeks, and eroding cliffs and shorelines all contribute. But because of the protective rocks and seawalls that extend southward from the Santa Barbara county line, much of this sand is now directed offshore.

"There are 11.5 miles of rock revetments upstream . . . and groins, jetties, and breakwaters downstream," said Steve Chase, assistant city manager for Ventura. ". . . The entire littoral [shore] is a joke."

Erosion adjacent to the groin at the end of the levee

Beaches exist in a state of "dynamic equilibrium." Sand is delivered, then moved about by daily changes in tides, waves, and winds. The rise in sea level, presence of dams and debris basins, and shape of the beach also influence the flow of this river of sand.

Beaches change from season to season. During the winter, when powerful storms blow in from the North Pacific, large pounding waves scour the beach and deposit sand offshore. Subsequent waves break on these sand bars, dissipating their potentially destructive energy before reaching the beach.

During the calmer periods of late spring and summer, longer, more gentle waves move sand back to shore. The beach fills in just in time for the tourist season.

Ventura County's coastline has endured a long history of losses to the ocean. The 1995 pounding of the Ventura Pier —which is now under reconstruction—is perhaps the most dramatic recent example. But it is certainly not the first.

Storms during the winter of 1936 destroyed Pierpont's "Pleasure Pier" at the end of Seaward Avenue. A concrete boardwalk and 40-foot-wide Shore Drive were also engulfed as the sea reclaimed a wide swath of shoreline. Rather than fight the inevitable, many homeowners moved their houses inland as the ocean crept closer and closer.

In recent years, residents, aided by the city of Ventura, have replanted some of the dunes, which helps to hold the sand and has provided added security to the Pierpont community. Resident Teri Raley, who walks the beach frequently, observed "The dunes are six feet higher since '76 when we first moved here. The people who live on the beach used to have an ocean view from their first-floor rooms, but not anymore."

In years of relative calm, beaches retain more sand. Lulled by placid ocean conditions, developers overlook its penchant for destruction, and build in erosion-prone areas. Improvements to Surfers' Point in 1989 are a case in point.

Too Close for Comfort

Storms during the savage winter of 1983 had damaged an earlier bike path after just two years of service. Subsequent studies of the area recommended that any development along Surfer's Point observe a 100-foot setback from the high-tide line. Despite the empirical evidence, in the interest of recreation and tourism, the city of Ventura paid for a new bike path and parking lot immediately adjacent to the shoreline on the fairgrounds property.

Loss of bike path and hazard to recreation

Because of the strong likelihood of erosion, the California Coastal Commission designated the path and parking lot "temporary." Their lifespan was projected at 5 to 20 years. But like its precursor, the bike path suffered damage within just two winters.

Inundated with requests to fix and protect this popular feature, the city applied for an emergency permit to deposit rock boulders along the shore. The Coastal Commission denied the request as environmentally unsound. Yet days later, the city dumped huge granite boulders on the downshore side of the Ventura River. Chase conceded that building the revetment was "not a smart move." The structure not only exacerbated erosion downshore, but created conflict between the Coastal Commission on one side and the city and fairgrounds on the other.

Gary Timm, district manager of the Coastal Commission's Ventura Office, said his staff considered charging the city with a violation, but determined there were complicating factors. The rocks, Timm said, were dumped above the mean high-tide line, which was within the city's jurisdiction under the Local Coastal Plan (LCP), but the LCP clearly states that revetments and other protective devices are not allowed on the beach, so the city's wall building was in violation.

"We concluded that if they were going to keep the rock there, they should get a permanent permit, which was subject to appeal," said Timm. "We told them we would appeal it as soon as they issued the permit."

The city applied for the permanent permit, the Coastal Commission staff appealed, but their bosses—the coastal commissioners—would not deny the permit, telling everyone concerned to work it out. "It's not resolved; I guess that's the bottom line," said Timm. "The rocks are still there and there hasn't been a permit or an LCP amendment."

The revetment has hastened the erosion of downshore dunes by high waves. Since its installation, more than 60 feet of bike path and parking lot have since cleaved into the ocean. Today, an inland migration of concrete barricades and fences that delineate the jagged bike path mark the passing of each big storm. Virtually unusable in its current state, the path and parking spaces at the upper end of the lot continue to disappear into the surf.

A study funded by the city of Ventura in 1993 evaluated several projects aimed at solving erosion problems at Surfers' Point. One was a return to 1989 conditions, which would require filling the eroded areas and protecting the immediate shoreline with a cobble berm, a rock revetment, or a stepped seawall. Costs for these barriers, not including permits and future maintenance, were estimated at $1.2 million for the berm, $2.2 million for the revetment, and $3.6 million for the seawall. Another option, demolishing the fractured bike path and relocating it to Shoreline Drive, would cost $119,000.

Looking for Compromise

In an effort to resolve conflict between the city and the Coastal Commission and solve the erosion problem, State Senator Jack O'Connell formed a "working group" in early 1995. It included representatives from the offices of Assemblyman Brooks Firestone, the city of Ventura, state Fairgrounds, California Department of Parks and Recreation, California Coastal Commission, California Coastal Conservancy, and the Surfrider Foundation. Marc Beyeler of the Coastal Conservancy served as facilitator. The group considered two options: 1) hardening the coast and rebuilding the bike path and parking lots at their original sites, or 2) relocating the bike path to Shoreline Drive.

After much discussion, the working group still could not agree on a solution. The majority preferred relocating the bike path landward, because it was the cheapest and most environmentally sound. But the fairground board of trustees didn't go for it. Their desire to restore the property to its 1989 condition and protect it from the sea with rocks, squelched consensus.

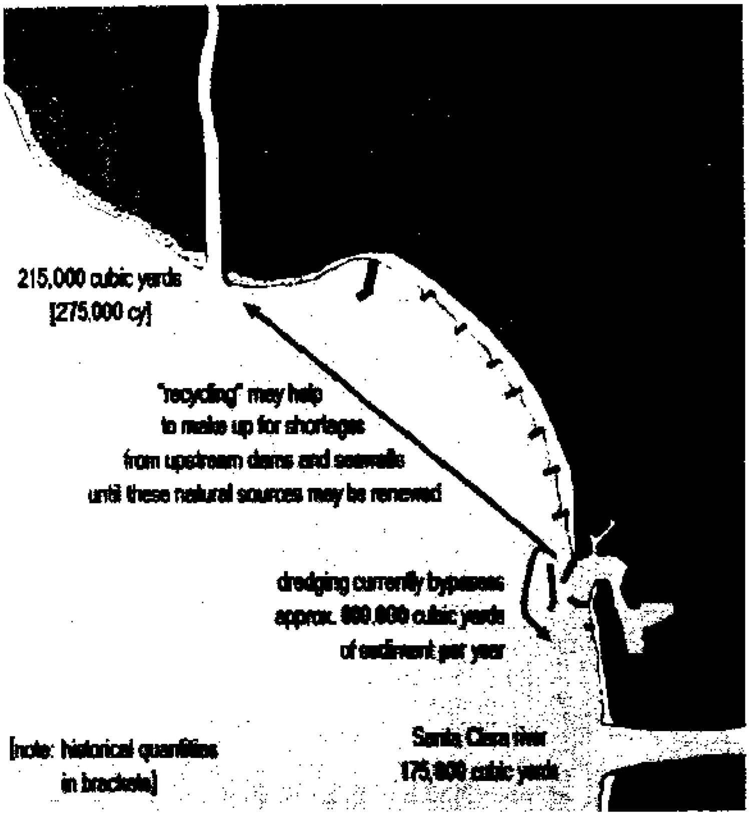
As a result, the working group disbanded late in 1996, and nothing has been done since. Representatives of the fairground did not return phone calls. Kris Kuzmich, an aide to Senator O'Connell, said her boss "expresses a high degree of frustration in the matter." All the parties involved appear to echo the sentiment. Everyone but the fairground board acknowledged that another seawall would likely spell more trouble for Ventura's downshore beaches. Further loss of sand would likely jeopardize the storm-plagued pier, the state beach, as well as Pierpont beaches. Would more rocks and seawalls necessarily follow, armoring the coast all the way to Ventura Harbor?

Like an abandoned car, the revetment is illegal, and it doesn't appear to be going anywhere. But the bike path and parking lot do.

Getting Soft

Given the destructive nature of armoring the coast, "soft" approaches are gaining ground. The idea is to maintain the buffering ability of the beach by adding sand to it.

To aid in a "managed retreat" of the bike path and parking lot, and help restore the area around Surfer's Point, there has been talk of "backpassing" some of the sand now dredged from the mouth of Ventura Harbor west to the popular recreation area. Recycling sand would also help to restore the eroded dune area and provide additional material for the beaches between the river and the harbor.



Dredging consultant, Richard Parsons, said that sand grain size would not be a problem; money is the big consideration. He suggested that further studies may be needed. "If the sand would all be back at the harbor in a year, it would not be a good expenditure of money," Parsons said. "But if it took five years, it may be worthwhile."

Each year, an average of 540,000 cubic yards of sand are dredged from Ventura Harbor and bypassed down to the mouth of the Santa Clara River at a cost of $1.5 to $2.5 million. Parsons estimated that it may cost another half a million dollars to redirect the sand upcoast.

Brian Brennan, former president of the Ventura County Chapter of the Surfrider Foundation and now a candidate for Ventura City Council, has long supported such soft solutions. He expressed excitement at the prospect. "The hope is that replenishment will help the beach heal itself," he said.

Parsons noted that the levee at the Ventura River also should be studied to determine if it needs to be modified. It is believed that because of its current configuration, sand brought to shore by the Ventura River may be pushed out to sea, rather that nourishing the starving beaches at Surfers' Point.

Bailard concurred, saying "With the current configuration of the jetty at the rivermouth, the area will always have scouring. The jetty is at the wrong place and the wrong angle."

Let It Flow

The Surfrider Foundation, an environmental group devoted to ocean related education and protecting beach and ocean resources, would eventually like to see the release of inland sand supplies now held back by dams. Twenty miles up the Ventura River, more than 11 million cubic yards of sediment lie trapped behind Matilija Dam. The material represents the accumulation of almost half a century of sand that Surfrider and others say should be on the beaches.

During the life of Matilija Dam, heavy siltation and structural defects have reduced the water storage capacity by more than 90%. With Lake Casitas now serving as the area's primary reservoir, Matilija has been rendered obsolete for anything but flood control. Proponents would like to see its removal, which would allow sand to flow freely to the beaches. It would also provide access the endangered steelhead trout with access to its historic breeding grounds in the upper reaches of the watershed.

While dam building has been a popular pastime during the last century, dam removal is a relatively new idea. A study of the Ringe Dam in Malibu, which is similar in size and scope to Matilija, estimates that dismantling the dam would cost anywhere from $10 million to $20 million. While this would seem to be a large sum of money, the artificial nourishment of regional beaches to make up for the shortfall of river sediments runs as high as $5 million per year.

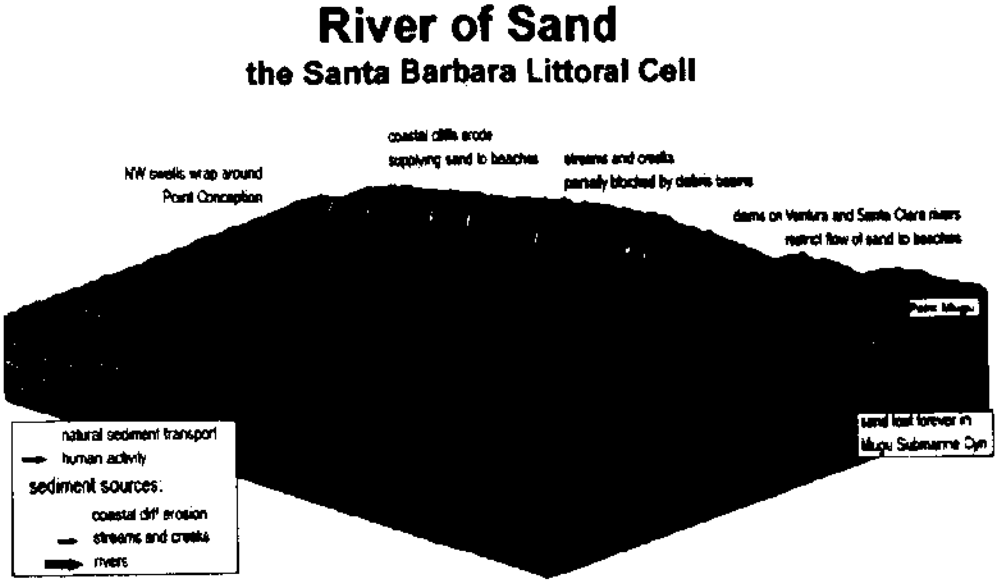
When people build too close to the beach, the threat of damage from erosion eventually becomes a problem for the entire community. Costly protective measures are often footed by the taxpayer for the benefit of the private property owner. The ultimate cost is the loss of precious beach.

Political stalemate has stalled any solution to the problem of erosion at Surfer's Point. Decaying asphalt, concrete barricades, and chain-link fences remain an unsightly reminder of a good idea in a bad place. As Chase put it, it is "a very precious resource that looks battered and torn." Meanwhile, the bike path sits at the edge of a restless ocean, which this winter, may be stirred by the most extreme storm season on record.

SIDEBAR

River of Sand

To understand coastal erosion it is first necessary to consider the bigger picture. Ventura County beaches are part of a larger system called the "Santa Barbara Littoral Cell," which includes the mountains and beaches stretching from Point Conception to Point Mugu. Rainfall and other natural forces erode the land, which flows down rivers and creeks to the beach in the form of sediments. Storm waves chew at coastal cliffs, which adds more material to the beaches. Longshore currents, caused by breaking waves, distribute this material along the coast in a process known as "littoral drift."



River of Sand
the Santa Barbara Littoral Cell

In Ventura County we get sand from sources as far west as Point Conception. Since most of the waves that strike our shores emanate from the west, this "river of sand" flows toward the east. Sand that is on Ventura's beaches today will soon be in Oxnard. The analogy of the beach as a river of sand becomes most evident when rock jetties are constructed perpendicular to the shoreline. Designed to stabilize inlet channels or harbor entrances, they interrupt the longshore current. Sand accumulates in the harbor entrances and on the updrift side of the jetties, while downdrift beaches, starved of their sand supply, undergo increased erosion. In order to keep harbor entrances open for navigation and to nourish downdrift beaches, trapped sand must be removed and deposited down coast on a regular basis.

The importance of bypassing sand from one area to another became evident at Hueneme Beach during the summer of 1996, when waves generated by a large south swell stripped the beach. Located downdrift of the Port of Hueneme jetties, Hueneme Beach relies on sand dredged from the entrance of Channel Islands Harbor by contractors for the U.S Army Corps of Engineers. The dredging program normally requires 1.1 million cubic yards of material every 2 years at a cost exceeding $5 million. In 1995, federal budget cuts provided for only 40% of this amount. As a result, Hueneme Beach receded drastically, and required emergency sand replenishment before the sea reclaimed public and private properties.

The river of sand flowing south of Ventura Harbor amounts to roughly 1 million cubic yards per year. To give some perspective, a large dump truck holds about 10 cubic yards. One million cubic yards of sand per year is equivalent to 100,000 truck loads, or 1 load dumped every 5 minutes around the clock all year long.

All this sand eventually makes it as far as Mugu Canyon, a huge submarine trench that comes to shore near Mugu Lagoon. At this point, the sand flows down into the deep ocean, forever removed from California beaches. Film footage has shown the river of sand disappearing down such canyons.

The river of sand is in constant need of new supplies to maintain the beach, but human activity has greatly altered the natural system. During the past 50 years large quantities of sand have been trapped by river dams. Today, about 42% of the Ventura River watershed is blocked behind such structures at Matilija Canyon and Lake Casitas. It is estimated that they deprive the coast of 30% of the sediments historically provided by the Ventura River.

Large quantities of sediments also are trapped by flood control debris basins on smaller streams. Worsening matters, private industry has a history of mining riverbeds for sediment originally destined for the beaches.

Raising the Stakes

If you haven't heard of the El Niño phenomenon by now, perhaps you had your head in the sand. An increase in the frequency and severity of this oft-discussed shift in weather patterns associated with warm ocean waters off the coast of Peru, is also thought by some scientists to be connected with global warming—a controversial theory that such human activities as the burning of fossil fuels are increasing global temperatures. The extent of this effect has yet to be determined. It is a fact, however, that the planet has been warming steadily since the last ice age.

Warmer temperatures melt polar and glacial ice, adding large volumes of water to the oceans. The resulting rise in sea level has been estimated at 6 inches per 100 years since the end of the last ice age, about 17,000 years ago. A recent UN study on global warming suggests that sea level may rise as much as two feet by 2040. This relatively rapid increase, combined with increased storm activity, spells more bad news for the already stressed coastlines of the world.

Increased sea levels will mean even more erosion. A USC study released this year estimated that over the next 50 years, southern California's shoreline might move landward as much as 75 yards. If that's the case, tough public policy decisions will have to be made as to how best to protect beachside properties and manage the beaches.

CAL-COAST

Robert E. Eichblatt
City Engineer, Huntington Beach, California

In April of 1997, I attended a dinner sponsored by the California Shore and Beach Preservation Association (CSBPA). During the dinner, I heard a very illuminating presentation on beach erosion and restoration by Dr. Craig Everts, a recognized coastal scientist. Kim Sterrett of the California Department of Boating and Waterways also discussed an economic study which is being prepared by the University of San Francisco. The study emphasizes how vital our beaches and our coast are, not only to our environment, but also to the economy of the State of California.

I returned from that dinner shocked and energized. The Huntington Beach staff immediately formed a task force or strike team comprised of City staff and local coastal consultants. The consultants included Concept Marine, Moffatt and Nichol, Noble Consultants and Bob Fisher. The team drafted a preliminary strategic plan for developing a coalition for advocacy of grant programs dedicated to coastal restoration.

What do we know about our California coast? California has 1067 miles of shoreline. These are the most heavily used recreational areas in the State. In addition to recreational opportunities, our coast provides a critical habitat. Our beaches have a greater annual attendance than Disneyland, Disneyworld and all of our national parks combined. Nine out of ten California residents visit our beaches each year. Over 500,000 California jobs are supported by coastal tourism. That represents 3 1/2% of all jobs in the State.

Our beaches drive the California tourist economy. They generate over $1 billion annually in total tax revenue. What if all that tax revenue were to be returned to our beaches for on-going maintenance and rehabilitation? Beach-goers spend over $27 billion annually. That is 3% of total economic activity in this State.

Approximately 925 miles of California shoreline continue to erode. However, California ranks last in the nation in coastal restoration spending at $0.07 per capita annually. The state of Delaware ranks first at $4.28 per capita annually. A recent survey indicates that beach-goers would be willing to pay as much as $25 per capita annually. If Assembly Bill 1228 sponsored by Assemblymember Ducheney had passed, it would have provided $15 million or only $0.46 per capita annually. We would have still been last in the nation.

In order to increase shore restoration funding to a reasonable level in this State, Huntington Beach and other organizations are considering forming a coalition to support advocacy. We are considering a tentative name of "Cal-Coast" or the California Coastal Coalition. This organization could possibly be a California branch of the American Coastal Coalition.

In the next few months, we will be accepting membership applications. We are also exploring the creation of a new Coastal Cities Division of the League of California Cities.

Any encouragement or innovative proposals would be greatly appreciated.

SAND RIGHTS AND SAND RESPONSIBILITIES

Orville T. Magoon
President, Coastal Zone Foundation

Billy L. Edge
Professor, Ocean Engineering, Texas A&M University

My remarks today reflect on the saying of the American cartoon character "POGO," who once said "I've met the enemy and he is us." I have often wondered why our message of concern for our shores, particularly our beaches, seems either to be not heard or not understood. Think for a moment of issues that galvanize the American — and much of the world's population.

For example, concerns over loss of the rain forests — much of the area of the rain forests are not in America — but in the tropics — far away from the world's urbanized areas. But we have all seen photographs in magazines, documentaries on television, and countless articles in our newspapers and magazines. Millions of dollars are being spent on rain forest related efforts — both to save the rain forests and also to educate.

Think also of the great campaign to save the coral reefs — stories, books, films and press on the "Year of the Reef." And again, most of the worlds Coral Reefs are also far removed from the USA mainland.

And in California, the listing of some important anadromous fish as endangered provide a great push to save these unique fish — hopefully to ultimately increase their populations so once again they will provide for much needed fly fishing recreation and hopefully someday, for commercial fishing.

Well, if all that attention can be focused on reefs, rain forest, and anadromous fish, why can't that same type of energy be focused on our beaches and coasts? To be perfectly frank — I don't know the answer to that question. But I would like to tell you what I think and also hear your thoughts on that issue.

One of the reasons is in part that we have tried to focus too strongly on the economic or dollar value of the coasts. After all, many of us have a "technical" or "numbers" background. We may understand benefit to cost ratios and recreation days. But we don't understand those important "C" words -- Communication and Compromise.

How far do you think the "Year of the Reef" campaign would go if we only focused on benefit to cost ratios or visitor days?

How far do you think the "Save the Rain Forests" campaign would go if we only focused on benefit to cost ratios or visitor days?

Perhaps we are trying to understand and justify coastal beach restoration with a band-aid approach. And if works of man are destroying our beaches — then the projects or actions that have caused reduction in sand supply should be refurbished to bring back the sand and coastal sediments to the coast and beaches.

Of course placing sand on the coast as beach fill helps — we get a beach now, but over time we lose the beach again. Why — because the sand is going away faster than it is being replaced. Each coast, each stretch of beach, is different, but as you know, sand grains just don't disappear. They went somewhere or someone or something "has" them.

We know that "beach erosion" has many causes and one concept or solution will not solve all our problems. But I believe that much of what we call "beach erosion" is due to works of man — a lack of sand problem.

When I talk beaches, I'm not just talking about ocean beaches, I'm talking about bays, rivers, estuaries, lakes and ponds. Many or perhaps most of you have never heard of "Clear Lake" in Lake County, California, but shortly I'll show you a headline from a local paper about restoring a beach on Clear Lake.

In our long-range goal of stable coastlines, we must think of many elements of the solutions, management, regulation, scientific studies and research and getting the sand back to the coastlines.

One basic need is for the public to have a place to recreate. On Los Angeles County beaches alone there are over 60,000,000 visitors a year and then there is Orange County and San Diego County. In total, well over 100,000,000 visitors per year.

With the rapid increases in population in coastal American, and the increase in leisure time available for many, especially our retired or senior citizens, the expectations for recreational opportunities is far out pacing the capacity for providing a place to play or walk — on a coastal "back yard" for urban dwellers. Professor Billy Edge and I are working on a publication on urban beaches. We would be glad to hear from any of you who would like to contribute to this effort.

Why don't we have enough sand on our beaches — or why is the sand in the wrong places? Let's look at one example in Southern California. In the greater Los Angeles area — actually in Orange County, Riverside County and San Bernardino County, there is a very large drainage area, largely urbanized or urbanizing, that has a potential for great and disastrous floods. This is the Santa Ana River Basin. In order to prevent flooding of this urban megalopolis, which is part of the economic heart of Southern California, a great flood control project was built — and is being further extended and includes Prado Dam and the new Seven Creeks Dam, miles of concrete channels, and a host of other hydraulic elements.

The project cost is in the billions of dollars. The benefits of this project measured in damages prevented, in one disastrous flood, could probably justify this entire project.

Well, the impact of this great project on the downcast beaches is that the dams, concrete lined flood control channels, and adjacent sand mining have, or will soon stop, all sand transport to the beaches that received the sand before works of sand were constructed. Much of the sediments that would have been supplied to the beaches are trapped in the dams and nearby channels and are removed for fill or simply remain in the project.

Farther north, near the mouth of the Columbia river on the state of Washington coast, across the Strait of Juan De Fuca, sediment derived from the Elwha River traveled to the coast which supplied Ediz hook which protected Port Angeles Harbor. After two concrete dams for power generation were built some 50 years ago, the migration of anadromous fish in the Elwha River stopped and the supply of sediments was greatly reduced. Recently, the U.S. Congress passed legislation which authorized the removal of the dams on the Elwha River. The removal of the dams is expected to increase the supply of sediments to the coast.

Sand mining in Monterey Bay, California has been another activity that removed large quantities of sand from the coast. Sand mining activities near Sand City, just north of Monterey, started operation in the early 1900's and have removed sand primarily for construction materials.

What are the solutions? Compromise and Communication.

In the California Gold Rush days of the 1840's and 1850's water became a precious resource as there was not enough to supply all the needs of the time. Water rights and water laws had to be formulated to prevent water wars and to allow the commerce of California to continue.

The Resources Agency of California now has developed a comprehensive set of rules and policies that allow for allocation and management of California's Water Rights. Perhaps no one is completely satisfied with these rules, but all water users can find a way to resolve their differences, and at the same time provide for the economic, environmental and water needs.

I think it is time for a new set of rights — Sand Rights. The first reference I could find on Sand Rights was in the July 1935 (Volume 3, Number 3) issue of *Shore and Beach* magazine. Another early reference to sand rights is found in *The Statutes of Nova Scotia*, Canada in 1975. And along with Sand Rights — Sand Responsibilities. First cut statements for Sand Rights and Sand Responsibilities follow:

Sand Rights

Human and human induced actions will not interfere, diminish, modify, or impede sand and other sediments or materials from being transported to and along beaches, shores, flowing or eolian paths or bodies

Sand Responsibilities

Human and human induced actions will not cause, accelarate, increase or modify sand, or other materials to be transported at a greater rate or extent than under natural conditions. (i.e.: into navigation channels)

And we can't forget communications. My wife Karen has produced a little booklet for children about sand's rights. I'd like to see this booklet, with a set of training guidelines, in every American child's school program. Our entire nation, and yes, the entire population of the world has a responsibility to love and take care of our beaches and shores.