Title
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Permalink

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Publication Date
1991-07-01

Data Availability
The data associated with this publication are available upon request.

Reprinted from The California Coastal Zone Experience
Coastal Zone '91 Conference-ASCE
Long Beach, CA/July 1991

SHORELINE EROSION ASSESSMENT AND ATLAS OF THE SAN DIEGO REGION

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Abstract

The California Department of Boating and Waterways (CDBW) in cooperation with the San Diego Association of Governments (SANDAG) and in consultation with the California Coastal Commission and the US Army Corps of Engineers (CE) are conducting an assessment of shoreline erosion in the reach from the Mexican border to Dana Point in Orange County (Figure 1). The assessment will form the technical basis for a local Shoreline Preservation Strategy currently under development by SANDAG with sponsorship from the State of California and the CE. The strategy will outline the alternative financial and institutional arrangements available for supporting feasible engineering solutions to beach erosion in the area. The strategy will include a public education and participation element, as well as an implementation plan. The erosion assessment study utilizes the many existing, detailed technical and scientific studies of all aspects of the local shoreline, as well as the results of the 8-year CE Coast of California Storm and Tidal Wave Study completed in 1991.

The assessment will include a detailed inventory of existing coastal protection structures and a discussion of their effectiveness in deterring erosion, a list and description of "critical" erosion areas that may require remedial protection in the near future, and a discussion of the engineering alternatives available at each site. The selected alternatives will be both financially feasible and environmentally sound. Results of the study will be summarized in a set of overlay maps that together will comprise the atlas. The feasible engineering alternatives for each problem area will differ, but are anticipated to generally include some combination of sand nourishment and engineered structure. Technical reports that will act as a background for the recommended engineering solutions include a description of the relevant coastal processes in the three littoral cells of the study region and a detailed inventory of the geological hazards.

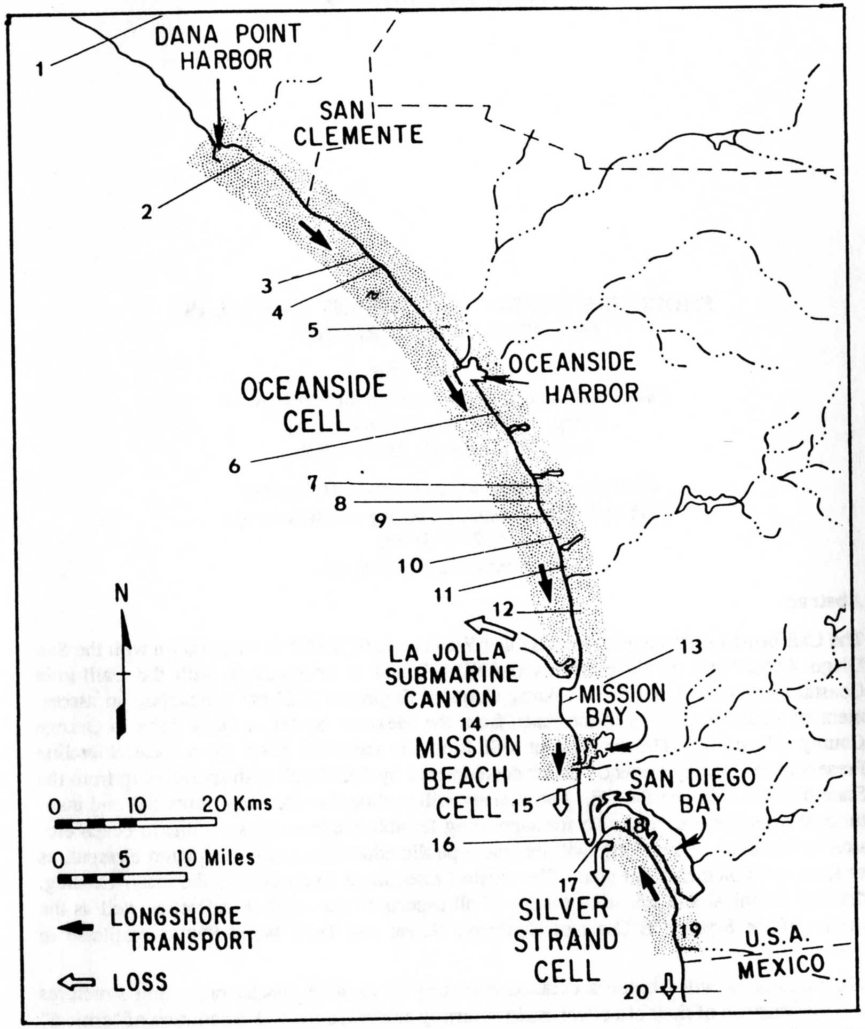

Figure 1. *Location map of the San Diego region study area including the coastal reach from the Mexican border to Dana Point in Orange County. Shading indicates the three major littoral cells of the region and the arrows show the idealized, wave driven longshore transport of sand on the beaches.*

Location key: 5 Camp Pendleton, 2 Capistrano Beach, 9 Cardiff, 6 Carlsbad, 18 Coronado, 11 Del Mar, 8 Encinitas, 19 Imperial Beach, 13 La Jolla, 7 Leucadia, 13 Mt Soledad, 17 North Island, 15 Ocean Beach, 1 Orange Cnty, 14 Pacific Beach, 16 Pt Loma, 13 Rose Canyon, 3 San Mateo Pt, 4 San Onofre, 10 Solana Beach, 20 Tijuana, 12 Torrey Pines, 17 Zuniga Jetty.

Introduction

Shoreline erosion has been a vexing problem at numerous locations in the San Diego region, particularly since much of the shoreline has been developed by public and private interests since the end of World War II. With increased insights into natural coastline processes, and with what appears to have been a shift away from an episode of relatively mild climate that prevailed from the late 1940's to about 1978, much of this development now appears to have been less than prudent. This is true of both public and private improvements that were built too low or too close to the beach, or with insufficient setback on cliffs. A series of severe winters in 1978, 1980 and 1982-83, with heavy rains, consecutive storms that produced high, long waves and elevated sea levels and at least one winter, 1988, with an unusually intense storm, produced hundreds of millions of dollars of damage and flooding in Southern California, with a proportional share in San Diego. These events heightened local residents' and governments' interest and awareness in shoreline erosion. The CE Coast of California Study arose in the early 1980's as a result of political pressure by local parties to conduct a comprehensive regional review of the problem. With the well-publicized threat of global warming and attendant sea level rise, the interest in long-term, viable solutions to shoreline erosion, as well as the actual danger of enhanced erosion rates, has also increased.

In response to these concerns, the California Department of Boating and Waterways (CDBW) in cooperation with the San Diego Association of Governments (SANDAG) and in consultation with the California Coastal Commission and the US Army Corps of Engineers (CE) are conducting an assessment of shoreline erosion in the Southern California coastal reach from the Mexican border to Dana Point in Orange County (Figure 1). The investigation is authorized under California Assembly Bill 761 which provided an appropriation of $130,000 from the state General Fund. The bill was sponsored by Assemblyman Robert Frazee and approved by former Governor George Deukmejian in September 1989. Of the appropriated funds, $70,000 were allocated to CDBW and $60,000 to SANDAG.

The role of CDBW is to develop a detailed assessment of shoreline erosion in the study area and to display the results in the form of an atlas analogous to, but with greater detail than, the one prepared by Habel and Armstrong (1977) for the entire California coast. The atlas will include a step-by-step description of each sub-reach in the study area, an evaluation of the potential for future erosion as well as a complete inventory of existing shore protection structures and a judgement of their effectiveness. The atlas will be based on examination of historical photographs and other documentary information such as structure plans, and a systematic ground reconnaissance inspection of the entire reach. This will serve to identify and document the degree of present or potential erosion at each site along the coast and to isolate the areas of critical concern. The project will provide recommendations for engineered structural and non-structural solutions to present or potential erosion problem sites, with particular emphasis on the critical areas.

The assessment and atlas will summarize the necessary basic technical information which is available from many years of studies carried out in the area (CE, 1986) and on which SANDAG can base it's Shoreline Preservation Strategy. The strategy will include recommended financial and institutional alternatives for implementing the engineering solutions proposed. Possible sources of existing, primarily state and federal, funding will be identified. Innovative local sources of funding such as assessment districts, transient occupancy taxes, user fees and participation by existing local or regional agencies like port districts, will be examined. Additional effort by SANDAG will include identification of all federal, state and local government agencies that play a role in shoreline preservation and management or have an impact on shoreline erosion.

The strategy will also suggest new institutional structures such as joint powers agencies which could assist in the regional implementation of shoreline preservation and erosion control policy. The effectiveness of existing laws, regulations policies and practices of all levels of government will also be studied with respect to their impact on implementing sound coastal engineering solutions. SANDAG is expected to play a key role in evaluating, comparing and selecting alternative feasible solutions on the basis of their effectiveness, cost, ability to attract funding and ability to secure permits. Another important part of the strategy will be to suggest possible alternatives to coordinate efforts and to resolve conflicts between agencies concerned with implementation of the erosion control plan. Public education and participation through a series of workshops will form an important element of the strategy.

Regional Setting

The San Diego region, as part of Southern California, is located on the plate tectonic border between the North America Plate and the Pacific Plate and exhibits many features of it's collision coast past (Inman and Nordstrom, 1971). The area is geologically young with a rugged undersea continental borderland topography, a narrow continental shelf, steep coastal topography, and a series of elevated coastal wave cut terraces. These are clear remnants of the tectonic uplift associated with the collision coast history of the area over the past 100 million years, and with it's interplay with sea level fluctuations. As a consequence, the San Diego coastline is geologically active with the potential for erosion, slope failure and seismic activity. Abundant regional geologic data and studies are available and these will be important resources required as a foundation for land use planning decisions and engineering design criteria.

Most of the San Diego coastal reach is comprised of relatively narrow beaches with thin veneers of sand atop the Recent wave cut terrace backed by sea cliffs of various heights (Inman and Bagnold, 1963). Lagoons and river mouths with relatively narrow coastal valleys incise the cliffs at the shoreline at numerous locations. The alternately low and high topography of the area from Silver Strand and San Diego Bay to Point Loma, Mission Bay, Mount Soledad and Point La Jolla to La Jolla Submarine Canyon was formed as a result of the structural syncline-antisyncline characteristics associated with the Rose Canyon fault zone (Kennedy, et al., 1975).

The rock formations along the San Diego shoreline can be characterized as horizontal sedimentary arrangements of Cretaceous to recent age (CE, 1984). The cliffs are composed of a wide range of materials from mudstones and shales to lithified sandstones and contain various lenses of boulders, cobbles and shells. The cliff materials therefore span a wide range of grain sizes, and depending on the local tilt of the bedding, material of different hardness and size is subject to erosion. The cliffs vary in height from zero in the southern, generally flat relief portion of the reach, to a maximum of about 120 m at Point Loma, and around 100 m at Torrey Pines State Reserve. Most of the rest of the cliffs are from 5 to 20 or 30 m high at the coast. The lower lying areas are comprised of loose to well consolidated silt, sand and cobble alluvium. On the beaches, this material is sorted by the moderate to high energy wave action that is the dominant physical driving force. The fine material is generally washed away leaving a veneer of sand 2 to 3 m thick in most places overlaying one or more layers of cobble on a bedrock terrace.

As shown in Figure 1, the study region can be conveniently divided into three littoral cells after Inman and Frautschy (1965). These are the Oceanside Cell, extending over 80 km from Dana Point to La Jolla Shores, the Mission Beach group of cells, including the rocky headlands of La Jolla to the Mission Bay entrance adjacent to the San Diego River mouth, and the Silver Strand Cell extending south from Zuniga Jetty at the entrance to San Diego Bay, to at least the Mexican border. A littoral cell is defined as an isolated geographical compartment, which in the Southern California example, is usually bounded by headlands and a submarine canyon, and that contains a complete cycle of sand sources, transport paths and sinks. Each of these cells contains a number of sub-cells or otherwise identifiable sections that are briefly detailed below.

Geologic Hazards

The geologic hazards within the area of interaction of the ocean and the land include beach and cliff erosion, strong seismic induced ground motion, slope failures, potential liquifaction and the threat of a locally generated tsunami. Beach and cliff erosion occur on a broad range of time scales and are usually related to severe winter storms, high rainfall, high tides and elevated sea level (Flick and Cayan, 1984; Seymour, et al., 1984). Beach erosion must be carefully distinguished from normal, seasonal beach width fluctuations and longer, interannual changes that occur as a response to varying wave activity. Erosion of the cliffs is highly site specific and episodic (Kuhn and Shepard, 1984), with 1 or 2 m of retreat in a few days possible at one part of a property, and no retreat at all a few ten's of meters away (Harker and Flick, 1991).

A wide, sandy beach absorbs all the wave energy impinging on it and forms the coastline's natural barrier to wave attack. If sand supplies are inadequate to provide a sufficiently wide beach to dissipate all the available wave energy, the waves will strike the cliffs directly. Historically, the rivers have been the main source of sand for the beaches in the region (CE, 1990). Most of the sand is supplied to the coast during infrequent, large floods that occur in particularly rainy winters. Flood control and water supply dams constructed since the 1930's on all the major watersheds in the San Diego region have also had a detrimental impact on sand availability to the coast. During times of relatively calm winters, such as the period from sometime in the 1940's to about 1978, river flooding and sediment yield is reduced. During droughts, such as the ongoing 4-year episode currently underway, river yields of sand may be particularly small.

Much of the deficit in sand supply caused by these factors has been mitigated by the large amount of sand made available to various parts of the San Diego coastline by harbor dredging and other construction activities For example, about 26,000,000 m^3 of sand were placed on the shoreline at Silver Strand starting in 1946, when massive expansion of San Diego Harbor became necessary, up to the late 1970's for various other dredging projects (CE, 1990). Construction of the San Onofre Nuclear Generating Station on Camp Pendleton in north San Diego County yielded over 1,000,000 m^3 of beach sand between 1964 and 1984 (Flick and Wanetick, 1989).

The steep coastal cliffs are geologically unstable primarily because most of them are relatively friable sedimentary structures, not hard igneous or metamorphic rocks like granite. Further, many sites are heavily faulted, fractured and cracked. These breaks and joints are weak and are easily undermined by wave action, forming caves and arches which periodically collapse, causing the upper cliff to fail also. A section of cliff at Torrey Pines collapsed in January 1982. This slide was about 160 m wide and averaged 8 m thick with a total volume of over 1,000,000 m^3. Many smaller slides and cave collapses occur all along the reach. Harker and Flick (1991) identified seven cliff failures that together contributed only 850 m^3 of sand to a 250 m long stretch of Solana Beach between about 1976 and 1989.

Subaerial erosion can be a significant factor where uncontrolled rain water and over-irrigation of landscaping causes gullying or cliff overwash. One notable event occurred at San Onofre State Park during a storm with intense rainfall in February 1980 when a small revine eroded landward about 75 m and yielded approximately 40,000 m^3 of sediment (Kuhn and Shepard, 1984). The coastal cliffs around San Onofre are particularly heavily incised with gullys and "barrancas" suggesting that subaerial cliff erosion in this area may contribute a significant amount of sediment to the local budget.

A set of important geohazards that may have been underestimated in San Diego until recently are those associated with earthquakes. There has not been strong ground motion, defined as accelerations greater than 10% of gravity, in San Diego from a serious earthquake since 1862 (Agnew, et al., 1979). Field work on the Rose Canyon segment of the Newport-Inglewood fault zone has yielded evidence of recent activity (Anderson, et al., 1989). Several dozen small earthquakes with magnitudes of 2 to 4 have been observed on this fault and in the offshore San Diego Trough over the past 60 years (Kennedy, et al., 1975). The Rose Canyon Fault is considered capable of significant surface displacement and strong ground motion. Major earthquakes have been recorded in the inland region along the San Jacinto, San Andreas and Elsinor Faults. The offshore area, especially the Coronado Bank Fault is considered to pose the greatest seismic risk to the San Diego coastal reach.

Strong ground motions manifest themselves along the coast with liquifaction and slope failures. Both responses can cause severe coastal damage with or without catastrophic failures, as the 1989 Loma Prieta earthquake in central California showed. Liquifaction potential maps have been prepared for San Diego, but many of the more vulnerable areas around San Diego and Mission Bays had already been developed before the threat was fully appreciated. The potential for cliff failure due to earthquake activity in San Diego is not well understood. Since San Diego has not been subjected to strong motion in such a long time, the cliffs may be more susceptible to failure than those in areas with shorter quake reoccurrence intervals.

The San Diego region has not experienced a damaging tsunami in recorded history. The orientation of the coastline and the presence of the offshore islands and shoals substantially shelters the shoreline from tsunami activity. The largest recorded event was associated with the Chilean earthquake of May 1960. The nearshore peak-to-trough wave height was 1.5 m and strong currents in San Diego Bay disrupted ferry service. The dip-slip type of faulting, with a large vertical component required to produce a locally generated tsunami event in the Southern California Bight has a low probability of occurrence. The dominant motions in the offshore continental borderland are strike-slip, with mainly lateral movement. This does not preclude the possibility of a locally spawned event, but merely points to the fact that more offshore geophysical surveying is needed in order to completely assess the risk.

Shoreline Description and Historical Changes

An accurately established and well documented history of shoreline change, including seasonal and extreme beach level variability, forms an important bases for managing the coast. In the San Diego region this kind of data is being used in the development of the Shoreline Preservation Strategy for the planning and functional design of structural and non-structural protection. Beach configuration, short term fluctuations and long term trends in sand volumes determine the design of beach fill projects, including the amounts and frequency of beach renourishment activities, and therefore the initial and recurring costs. Data used to determine these parameters include beach profile surveys, shoreline change maps and shoreline positions determined from aerial photographs.

The historical shoreline change rates for a number of sub-regions in the San Diego study area were quantified for the periods pre-1940, 1940-60, 1960-80 and 1980-89 by CE (1990) as part of the Coast of California Storm and Tidal Waves Study. The results for the three local littoral cells are summarized below.

Silver Strand Littoral Cell - This sub-reach consists of a 22 km arcuate beach and barrier system extending from the northern outskirts of Tijuana, Mexico through Imperial Beach and Coronado to the Zuniga Jetty at the eastern side of the San Diego Bay entrance channel (Figure 1). The longshore transport of sand is generally to the north because the incoming waves from the north are effectively blocked by Point Loma. There is a nodal point of zero net longshore transport in the southern part of the area that moves depending on the wave directional climate. Late 1800's photographic evidence from the vantage of the Hotel del Coronado suggests that the spit separating the ocean from the bay was narrow and a marginal barrier that was occasionally breached by storm waves.

CE (1990) data suggest that the pre-1940's shoreline was stable, on the average. In early 1905 there were severe south approaching storm waves that caused a large beach retreat and a 3 m high scarp at Coronado. A rip-rap seawall was built soon after north of the Hotel del Coronado to protect the public roadway. Between 1940 and 1960 there was widespread accretion north of Imperial Beach at rates of about 6 m/yr because of the massive beach nourishment associated with the San Diego Bay dredging already mentioned. This resulted in extremely wide beaches by Southern California standards at Coronado and North Island, the downdrift end of the cell. During this same time, there was erosion at Imperial Beach to Playas de Tijuana of order 2 m/yr.

From 1960 to 1980 the area was fairly stable, with the exception of Imperial Beach, where retreat accelerated to a rate of about 4 m/yr. This reflected sand shortages developing as a result of damming the Tijuana River on both sides of the border. Many suggestions were made about how to fix what was becoming a chronic erosion problem at Imperial Beach, and these efforts culminated with the proposal of an offshore breakwater. Construction was about to begin when a law suit by environmental and surfing interests halted the project in the mid-1980's. During the most recent period, 1980-89, the area has been mostly accretional, with a 6 m/yr shoreward advance at Imperial Beach, and Coronado. The Tijuana River mouth was the only area that retreated, with an average erosion rate of over 4 m/yr.

Mission Bay Littoral Cell. - This cell includes Ocean Beach, Mission Beach and Pacific Beach located between the rocky cliffs of Point Loma and the headland at La Jolla to the north. The main feature is the Mission Bay small craft harbor built in the 1950's with it's 300 m wide entrance channel and two jetties that extend over 500 m from the beach. A shorter, third jetty acts to confine the mouth of the San Diego River which exits adjacent to the entrance channel. The area is essentially a 5 km long pocket beach (Thompson, 1987) trapped between Point La Jolla and the jetties. The chief sand source is from nourishment activities incidental to harbor dredging and maintenance, with over 20,000 m^3/yr placed between 1951 and 1987.

This entire cell has been comparatively stable over the years, showing 2 or 3 m/yr accretion during the peak dredging of Mission Bay in the 1950's, and also comparable accretion rates from 1980 to 1989. Beach cleaning has caused some loss of sand in the area, estimated to be up to 20,000 m^3/yr (Hotton, 1988), but specified as 7,500 m^3/yr from 1975-88 by CE (1990). The area beaches are subject to substantial seasonal and inter-annual swings in width. Accretion up to 30 m and erosion down to - 40 m from mean beach positions have been recorded.

Oceanside Littoral Cell. - This is the longest sub-reach in the study area, extending over 80 km from Dana Point to Point La Jolla. The primary historical sources of sand in the cell have been the rivers and erosion of the cliffs, particularly in the northern segment. Large amounts of sandy material would reach the coast during large flood events, such as occurred during the heavy winter of 1916 (Inman and Jenkins, 1983). The sediment yield from the rivers has been cut by about half (Brownlie and Taylor, 1981) due to the construction of water supply and flood control dams. Much of the sand deficit that has resulted from dam construction as well as the milder average weather and consequent less severe flood flows, has been replaced by harbor dredging and other construction. For example, construction of Oceanside Harbor provided a total of over 9,000,000 m^3 of sand to this reach from harbor dredging between 1942 and 1988. An additional 750,000 m^3 of sand from a local river bed was trucked to the Oceanside beaches as nourishment in 1983. Cliff excavation and offshore dredging for cooling system pipes during construction of the San Onofre Nuclear Generating Station 25 km north of Oceanside, has provided an additional 1,000,000 m^3 of sand to the littoral cell between 1964 and 1985 (Flick and Wanetick, 1989).

A number of estimates of the sediment budget of the cell have been made (CE, 1987) with much study effort the result of political pressures and engineering requirements associated with the sand dredging and bypassing efforts at Oceanside Harbor. There are two sizable small craft harbors in the reach, Dana Point Harbor at the extreme northern end, and Oceanside Harbor in the middle (Figure 1). The harbor structures at Oceanside have contributed to a drastic mal-distribution of sand in the area by interrupting the longshore transport and diverting sand offshore (Inman and Jenkins, 1983). This has resulted in relatively wide beaches to the north of the harbor, and chronic sand deprivation on the beaches just to the south. Signs of sand shortage become progressively less obvious with distance south of Oceanside.

In the CE Coast of California Study results, the Oceanside cell is divided into six sub-reaches, La Jolla to Del Mar, Encinitas to Leucadia, Carlsbad, Oceanside, Camp Pendleton and San Mateo Point to Dana Point. This selection was based mainly upon geographic boundaries such as lagoon entrances, but is somewhat arbitrary. According to CE (1990), all portions showed a stable shoreline prior to 1940, with changes less than about 1 m/yr. The southern sub-reaches remained stable until the 1980-89 period, when large accretion rates of 3 to 10 m/yr were evidenced between La Jolla to Del Mar, most likely owing to the massive slides at Torrey Pines, mentioned above. At the same time, moderate erosion rates of 3 m/yr were experienced at Carlsbad, possibly all due to losses in the winters of 1980 and 1982-83 from which this location has not as yet recovered (Flick, et al., 1986). Some other areas south of Oceanside Harbor have eroded at rates exceeding 12 m/yr from 1980-89, possibly due to the same reason. North of the harbor, the Camp Pendleton sub-reach has mostly shown accretion over the later period of time, likely because of the littoral barrier at Oceanside and due to the construction activity at San Onofre, outlined above. The northernmost area from Capistrano Beach to Dana Point accreted up to 3 m/yr from 1960 to 1980, but has lately reversed this trend and is suffering erosion of about the same rate.

Critical Areas

The Coast of California Study, based on the analysis of historic shoreline and profile changes, identified only four areas in the San Diego reach that exhibit some coastal problems (CE, 1990). These areas and their vulnerabilities are summarized below from CE (1990).

Tijuana River Mouth to Imperial Beach. - This area is vulnerable to wave attack and maximum seasonal winter retreat approaching 50 m. Mean erosion rates at the present time (1980-89) are estimated to be about 1.5 m/yr with the loss of sand not confined to the beach face, but extending to at least 10 m water depth.

Coronado Beach - Although this beach is presently accreting, it is still assumed to be vulnerable, particularly to large waves from the south, since it is subject to large seasonal swings in beach width of ± 50 m.

Encinitas to Oceanside Harbor - This 20 km stretch is presently experiencing net erosion with rates varying by a factor of 40, depending on exact location. The lowest erosion rates range from 0.3 m/yr at Encinitas to about 1.5 m/yr at south Carlsbad. The rate increases rapidly to over 12 m/yr just south of the Oceanside Harbor structures, a distance of only 8 km from south Carlsbad. Much of the erosion trend is attributable to the series of severe winters from 1978 to 1988 already mentioned. Corrective action may require acceleration of the current, sporadic nourishment activities and modification of their design to increase the amount of course grained sand used. Nourishment programs may have to be supplemented with some engineered structures such as groins, revetments or offshore breakwaters in order to stabilize the most severely eroding areas.

Capistrano Beach - Localized erosion of about 3 m/yr has been recorded during the 1980-89 period along the approximately 3 km beach south of Dana Point. Additional profiles are needed to better establish this rate and the extent of the erosion.

It is anticipated that the detailed CDBW coastal reconnaissance presently underway will serve to identify other critical erosion areas in addition to those selected by CE (1990). For example, Imperial Beach, Silver Strand, the cliffs along Point Loma, parts of Mission and Pacific Beach, La Jolla Shores, Del Mar, Solana Beach and Cardiff have all had recent coastal damage and flooding. To a large degree, which areas are identified as critical erosion areas depends on the definition of "critical". The CE (1990) relied mainly on historical measurements of beach profile changes. Profile measurements are inadequate to completely define shoreline changes, since they are very sporadic, especially before 1982, and they are very poorly distributed spatially. Furthermore, shoreline change maps of cliff areas may not reveal the true urgency of erosion problems in some areas. For example, the cliff edge city street and numerous coastal access points in the northern part of Point Loma are constantly being undermined.

Many factors must be taken into account when assessments of "criticality" are made. These may include the degree of public and private investment, the possible alternatives to shoreline protection, particularly the feasibility of abandonment and the political, military, commercial, recreational, habitat or scenic value of a particular area. Some of these factors may be more important than others to different agencies and individuals. Developing criteria and definitions of critical erosion will be one of the important tasks addressed in the assessment study presently underway.

Shoreline Erosion Atlas

The shoreline atlas will consist of a set of base maps summarizing all the relevant information developed in the many previous studies (CE, 1986), the results of the Coast of California Storm and Tidal Waves Study and the data gathered by the CDBW field reconnaissance. Another set of maps will be devoted to the suggested beach nourishment and other engineered erosion control concepts that emerge from the assessment.

An important component of the atlas will be an inventory of all existing shoreline structures, including a brief discussion of their history and present effectiveness. There are a wide variety of structures present, and these fall into one of the following types: rock revetment with rock or sand substrate, reinforced concrete retaining wall on native material, stress wall placed on pile foundation with concrete cap and rip-rap toe protection, reinforced earth retaining wall on native or rip-rap substrate, H-pile beam bulkhead with timber lagging with bond beam and rip-rap toe protection, steel sheet pile either cantilevered or tied back, or various concrete gravity seawalls with wave deflectors. The atlas will also chart and discuss all the groin fields in the study area.

Historical and current sand nourishment projects will be identified in the atlas. This will form a useful basis for the proposed beach maintenance program, where sand nourishment will play an important role. For each target nourishment site, the atlas will list the required nourishment time interval, sand volumes needed, location of potential on or offshore borrow areas, proposed methods of transport, associated new structural components, if any and, of course, estimated costs.

A preliminary cost estimate projection for shore protection needs in California from 1990 to 1999 has been prepared by Armstrong (1990). The portion projected for the San Diego area is reproduced in Table 1.

Table 1. San Diego Region - Projected Shore Protection Costs

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Millions $	5.6	12.6	10.2	17.5	28.1	13.2	13.9	10.0	18.8	11.3

These estimates were based on the following criteria: the design beach would be 100 m wide with a foreshore slope of 20:1, the depth of fill would be about 2 m over the existing beach, for a unit volume of 200 m^3/m of beach at various renourishment intervals. It was assumed that sand cost $\$10/m^3$ and that if any stabilizing groins were required, that these would be 100 m long, spaced at 100 to 200 m intervals and cost about $4500/m. These cost estimates are preliminary and are presented only to illustrate the order of magnitude of the costs involved in local shoreline restoration and maintenance. These costs should not be construed as final, nor as estimates officially reviewed, approved or advocated by any government agency.

Acknowledgements

The authors are grateful to Mr. William H. Ivers, Director, and Mr. Bill S. Satow, Assistant Director, California Department of Boating and Waterways for their interest in this work.

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