BARRIER BEACH FEATURES OF CALIFORNIA

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INTRODUCTION

Remarkable near-continuous examples of barrier beach features are found in many coastal areas, worldwide. The most notable North American examples are the margins of North America along the Atlantic and Gulf of Mexico, where barrier islands are found along more than 60 percent of the coastline. There are, in fact, 280 large-scale individual barrier features, 70 of which are highly developed and 100 more are being developed (Hobson, et al, 1980). These barriers have been built out of the enormous volumes of sediment available from the extensive watersheds of eastern and central North America and, through the ages, appear to have migrated long distances across a wide continental shelf in response to the interplay of waves and tidal currents, eustatic sea level fluctuations and sand supply.

Barrier features are less in evidence on the west coast of North America though they are by no means absent. For example, along a 60-mile reach of the Oregon-Washington coast adjacent to the Columbia River mouth, impressive barrier spits have straightened the coast by blocking the bays and headlands. These are black-sand beaches, formed from the large sediment supply of the extensive inland basin of the Columbia (Bascom, 1980; Cooper, 1967), which has the 29th-largest discharge of the world's rivers (Inman and Nordstrom, 1971). The longest spit in this reach is about 19 miles long. The North Pacific coast is a high-energy wave environment, and these spits are continually shifting. Indeed, one of the most outstanding examples of continuing shore movement in North America is found at Cape Shoalwater at the north side of Willapa Bay, Washington where the inlet has migrated about 2.5 miles northward in the last 95 years across homesites, a cemetery and a lighthouse (Terich and Schwartz, 1981; US Corps of Engineers, 1971a).

CALIFORNIA BARRIER BEACH FEATURES

The barrier beach features of California, which are principally composed of quartz and feldspar sands, are proportionally less extensive, but are more common than is generally recognized. Out of an open mainland coastline of 1,073 miles, approximately 210 miles, or about 20 percent may be termed barriers. (By comparison, all sand beaches on the coastline total about 550 miles - U.S. Corps of Engineers 1971b; these figures exclude offshore islands.) This figure is based on barrier features identified during a reconnaissance-level review of existing base maps, aerial photography, historical reports, narrative coastal inventories, and limited on-site inspections. (Especially valuable were U.S. Geological Survey quadrangles, and the file of low-level 35mm photography of the entire California coastline maintained by the State of California Department of Boating and Waterways.)

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In all (see Figure 1), 181 separate barrier beach features were identified in California. Of these, 29 are highly developed with works of man, and 42 are partially developed. Of the total number, about 16 may be considered as major geological features with a length greater than three miles: these are commonly bay-mouth barriers and spits. The distribution of barrier length is shown in Table 1. The other features are generally small creek or bay-mouth barriers: some of which are to be found as an uncommon and analomous features on an otherwise rocky and precipitous coast and without sufficient drainage area to produce more than a relative modicum of sand. Barrier identification generally follows definitions by Shepard and others (Shepard, 1973; Putnam, et al, 1960) with a specific primary criterion that a coastal lagoon or inlet, marsh or permanent or semi-permanent wetland or water-body exists (or historically existed) behind part of the barrier; the barrier may be closed seasonally or permanently - as in the case of certain freshwater or brackish lagoons and lakes which have long been separated from the ocean. (The sheltered coastline of San Francisco Bay is excluded from this analysis.)

Table 1

Range of Lengths of California Barriers

Range	No. of Barriers In Each Range
0-1 miles	127
1-2	20
2-3	19
3-4	5
4-5	3
5-6	1
6-7	2
7-8	1
8 and up	3
	181 total

From north to south in California, a partial list of notable coastal barrier features include Big Lagoon; Humboldt Bay - the largest lagoon on the California coast (Shepard, 1973); Bodega Harbor; portions of Monterey Bay; Morro Bay; Los Angeles-Long Beach Harbor to Newport Bay; the Oceanside area, and San Diego Bay. Several of these are discussed below as case histories, with San Diego Bay being treated in more detail. Cenerally, it is true that these features owe their existence to plentiful present, or past, supplies of sediment and that extensive coastal wetlands and marshes with important wetland values are, or were, present in association with them. With the notable exception of the Los Angeles Harbor to Newport barriers which have been greatly modified, most California barriers still approximate their natural state insofar as coastal processes are concerned. However, the associated coastal marshes and wetlands have been greatly reduced by dredging, filling, and other urban activities, and many are also severely threatened by natural and man-induced sedimentation from upland runoff.

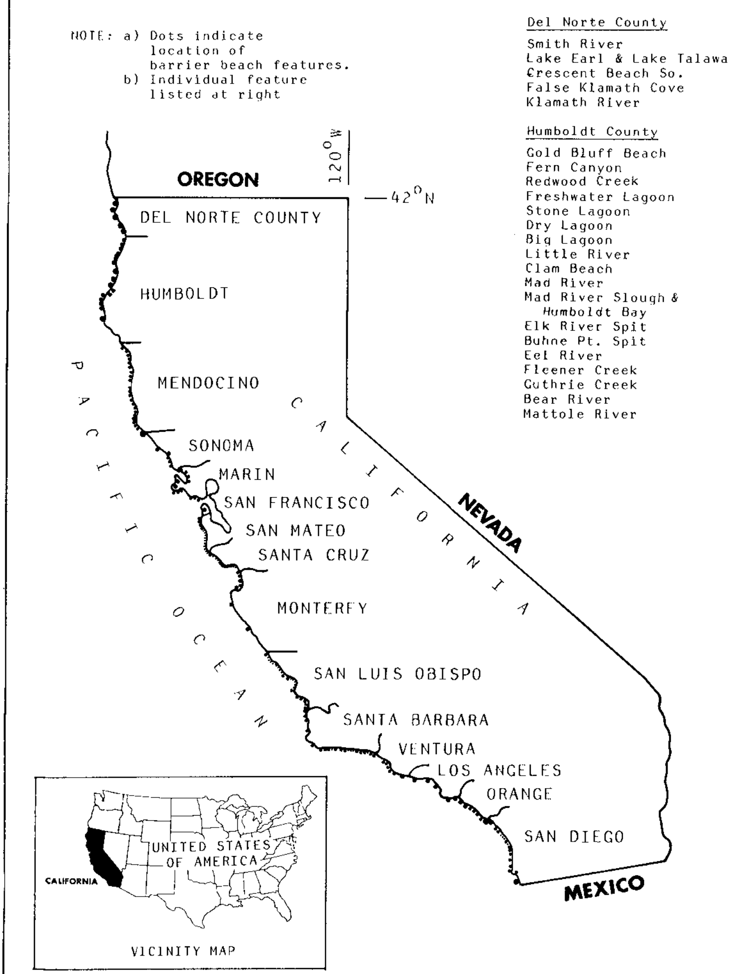

FIG. 1: BARRIER FEATURES OF CALIFORNIA BY COUNTIES

Mendocino County

Jackass Creek
Usal Creek
Cottaneva Creek
Hardy Creek
Juan Creek
Wages Creek
Ten Mile River
Inglenook to Lake Cleone
Virgin Creek
Pudding Creek
Noyo River
Caspar Creek
Big River
Little River
Albion
Big Salmon Creek
Navarro River
Greenwood Creek
Elk Creek
Alder Creek
Manchester Beach &
Garcia River

Sonoma County

Gualala River
Russian River
Scotty Creek
Salmon Creek
Salmon Creek Beach So.
Bodega Spit
Estero Americano

Marin County

Estero de San Antonio
Sand Point
Tom's Point
Kehoe Beach
Abbots Lagoon
Drakes Beach
"D" Ranch
Drakes Estero
Bolinas
Muir Beach
Tennessee Cove
Rodeo Lagoon

San Francisco City/County

Lake Merced

San Mateo County

Laguna Salada
Montara Beach
Princeton Marsh
Elnar Beach
Tunitas
San Gregorio
Pomponio Creek
Pomponio Beach
Pescadero Creek
Arroyo de los Frijoles
Mile Forty-three
Yankee Jim Gulch
Gazos Creek
Cascade Creek

Santa Cruz County

Waddell Creek
Scott Creek
Laguna Creek
Majors Creek
Baldwin Creek
Mile Seventeen
Dairy Gulch
Wilder Creek
Terrace Point
Younger Lagoon
Nearys Lagoon &
San Lorenzo River
Woods Lagoon/Santa Cruz
Harbor
Schwans Lagoon
Corcoran Lagoon
Moran Lake
Capitola
Aptos

Santa Cruz & Monterey Counties

Pajaro River

Monterey County

McCluskey/Salinas Slough
Salinas River
City Lands
Seaside-Monterey
Carmel River & San Jose Creek
Little Sur River
Big Sur River

San Luis Obispo County

San Carpoforo Creek
Arroyo de la Cruz
Arroyo del Oso
Arroyo del Corral
Oak Knoll Creek
Mile Sixteen
Arroyo del Puerco
Little Pico Creek
Pico Creek
San Simeon Creek
Santa Rosa Creek
Villa Creek
Cayucos Creek
Whale Rock
Willow Creek
Toro Creek
Morro Bay
San Luis Obispo Creek
Pismo Creek
Oceano Lagoon
Dune Lakes
Oso Flaco Creek

San Luis Obispo & Santa Barbara Counties

Santa Maria River

Santa Barbara County

Shuman Creek and Ponds
San Antonio Creek
Santa Ynez River
Jalama Creek
Cañada del Cojo
Cañada de Santa Anita
Cañada Del Sacate
Gaviota Creek
Refugio
Dos Pueblos Creek
Tecolote/Winchester
Devereaux Lagoon
Goleta Lagoon
Goleta Slough
Arroyo del Burro
Mission Creek
Andree Clark Lagoon
Carpinteria - El Estero

Ventura County

Rincon
Ventura River
Pierpont
Santa Clara River
McGrath Lake
Ormond Beach
Mugu Lagoon

Los Angeles County

Topanga
Malibu Creek
Ballona Creek
Rattlesnake/Terminal
Island
Alamitos Bay &
New River Slough

Orange County

Anaheim Bay
Bolsa Chica Beach
Santa Ana River
Newport Beach
Aliso Creek
San Juan Creek

San Diego County

San Mateo Creek
San Onofre
Las Flores Creek
French & Aliso Canyons
Cocklebur Canyon
Santa Margarita River
San Luis Rey River
Loma Alta Creek
Buena Vista
Agua Hedionda
Batiquitos
San Elijo
San Dieguito
Las Peñasquitos
La Jolla Shores
San Diego River &
Mission Bay
Ballast Point
North Island to
Tijuana River

FIG. 1 (Cont)

Most of the major barriers have remained essentially stable in shape and location during their recorded history, although some structures built on barrier beaches have been damaged during cyclic winter storms, and significant amounts of sand have artificially been placed on certain southern California barriers.

COASTAL ZONE MANACEMENT

Today, further building and development on California barriers, and beaches in general, is now constrained by strict State coastal zone management policies, which include regulations to protect recreational beaches and environmentally-sensitive habitat areas - such as barrier-associated coastal wetlands and marshes; and coastal hazard regulations which generally require that coastal structures be set back sufficiently from the shore so as not to be endangered by cyclical erosion (State of California, 1976).

The California Coastal Act of 1976, though of Statewide application, calls for the separate development and administration of Local Coastal Programs (LCP's) by local entities, consisting of land use plans and zoning regulations for upland areas (above mean high water). These programs are currently in process; to date about one-quarter of them have been approved by the State Coastal Commission (California Coastal Commission, 1979 and 1982), which still retains control of tidal and submerged lands below mean high water, including coastal wetlands and lagoons. In all, the 181 barriers identified in this review are variously located in many different jurisdictions. Within California there are a total of about 120 LCP's divided between 67 counties and cities, one university, and four ports.

Despite local differences in application, the net effect of these regulations will be to strictly limit development along California beaches, including the coastal barriers. Although it is yet too early to be completely sure, it appears that, under Coastal Commission and other State policies, major coastal structures are precluded except in port areas, or where an evident, water-dependent, public need, without a feasible alternative, can be demonstrated (California Resources Agency, 1978).

CASE HISTORIES

Long reaches of the California coastline are bordered by cliffs: either the steep faces of elevated marine terraces or the precipitous slopes of coastal hills or mountains. The open ocean coastline is, as indicated previously, fronted by sand beaches for about half of its length; many of these beaches are little more than a narrow strand along a steep or rocky backshore; wide, extensive sand beaches are generally only to be found where sizable streams or intermontane valleys come to the shore. Small barrier features may be found blocking small streams in many areas of the coastline, but longer, larger barriers are, of necessity, associated with more plentiful sand supplies from larger watercourses and drainage basins. Many barriers are also associated with hook-shaped bays which are an important and recurring feature of the California coast. These latter features occur in many areas of the world where a particular wave direction acts obliquely on the coastline over eons, resulting in indented hooked or crenulate-shaped bays in the lee of prominent headlands (Silvester 1974).

The following case histories (see Figure 3 - Note: Figure 2 deleted) include Humbolt Bay where protective barrier beaches occur along a long straight reach of sandy coastline. By way of contrast, barrier spits at Bodega Harbor, Bolinas Lagoon and the elongated barrier at San Diego Bay have been built by wave-induced currents acting in the lee of prominent headlands; these features follow the hooked form.

Humboldt Bay

This brief review of case histories of selected California barriers begins with Humboldt Bay, a shallow tidal estuary 230 miles north of San Francisco. The bay, with a high tide area of about 25 square miles, is separated from the ocean by two long barrier spits which in turn are separated from each other by a jettied entrance channel with a maintained 40-foot depth. A treacherous, shoaling submerged bar at the entrance requires large volumes of regular dredging. Both spits, especially the north, have active dunes. The north spit is about 8 miles long, and averages about 3,000-4,000 feet in width. Although largely open space, there are industrial and residential areas along the bayward side, as well as numerous roads. The south spit is about 4 miles long and narrow, ranging from 600-1,500 feet in width; it is maintained as undeveloped open space. The likely sources of material for these features are modern and prehistoric sands from the nearby Mad and Eel Rivers: the latter stream being a prodigious sediment carrier during flood periods (Welday, 1970). Overall, since the entrance was fixed by jetty construction in 1890, the north and south spits have advanced seaward (Noble, 1971; Kieslich, 1981; Shapiro, 1979); at present, the spits are in a state of dynamic equilibrium. Fixing of the jetties and subsequent deepening of the entrance channel concentrated wave energy on an elevated bluff area bordering the bay inside and opposite the entrance. As an apparent result, the area has retreated up to 1,600 feet since 1854, almost obliterating the bluff area, and lengthy stretches of the shoreline have been armored (Tuttle, 1982; Shapiro, 1979). Also, two relatively small laterally-moving spits have been created inside the bay, one to the north and one to the south, continually extended by materials moved by wave energy coming through the entrance.

The applicable Local Coastal Program of Humboldt County emphasizes protection of the spits as valuable open space and habitat area. This fact, coupled with their essential stability, indicates that the barriers will remain relatively unchanged over the next several years.

Bodega Harbor

Bodega Harbor is a small triangular-shaped coastal lagoon 55 miles northwest of San Francisco. The water area at high tide is about 1.3 square miles. The lagoon is located directly on the San Andreas fault zone and is separated from the Pacific on the west by a wide (2,500' wide and greater) tombolo-like sand barrier which links the

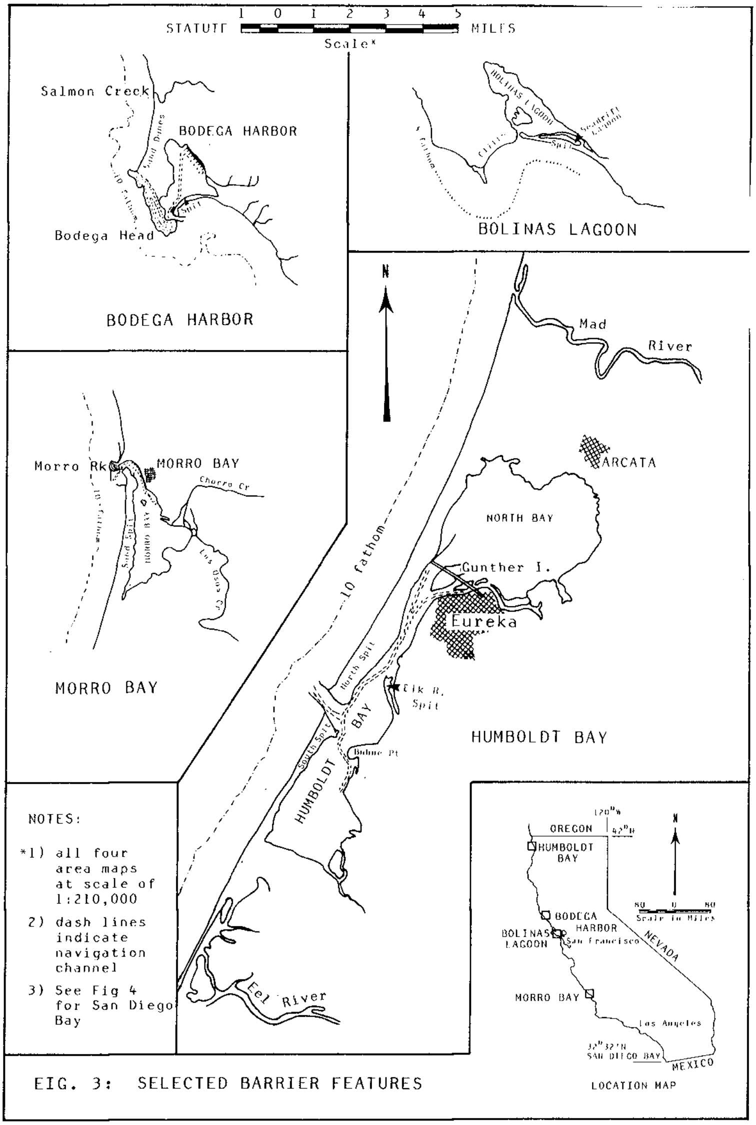

FIG. 3: SELECTED BARRIER FEATURES

mainland with Bodega Head, a rocky promontory to the west. To the south, the harbor is separated from the ocean by a much narrower curved barrier spit (600 feet or more in width), 1.6 miles long, with a jetty-protected entrance at the west end. The principle sources of the barrier sands are Salmon Creek and the Russian River, both to the north (Zeller, 1962). The entrance requires very little maintenance as the tidal prism balances the effects of wave attack. Past overgrazing had denuded the north barrier, resulting in movement of sand dunes and large volumes of sand blowing into the interior channels. In recent years, replanting of vegetation has stabilized the dunes resulting in lessened maintenance dredging. Filling of the harbor by landfills has also been halted.

The harbor area is an important recreational and commercial fishing center but developmental pressure is relatively low. The Local Coastal Program of Sonoma County provides for continuance of the barrier area as protected open space. The northern dune area is part of a State park and the curved barrier spit adjacent to the entrance is a County Park. Since both barriers are essentially stable, important physical changes are not expected in the foreseeable future.

Bolinas Lagoon

Like Bodega Harbor, Bolinas Lagoon is a triangular-shaped coastal inlet and is similarly located directly on the San Andreas fault zone, 15 miles northwest of San Francisco. The lagoon area is about 2.2 square miles. The lagoon is about 3.5 miles long by 1.5 miles wide and is separated from the ocean by a curving sand spit 700 to 1,500 feet wide and 2 miles long. An uncontrolled entrance to the lagoon is at the west end of the spit and is naturally maintained by the tidal prism of the inlet, though at a shoal depth. The tidal prism of the lagoon has been greatly diminished over the last century as agricultural and urban land use have resulted in accelerated sedimentation. Without watershed control of sediment loads, and possibly remedial dredging, the inlet will close and the lagoon will eventually become a meadow (Johnson, 1974). (As noted earlier, this is a general problem facing many lagoons in California.)

The primary source of material for the spit is northwest drift of material from the submerged bar (San Francisco Bar) offshore the Colden Cate and the cliffs to the west of the inlet entrance which are actively eroding (Wilde and Yancey, 1970). Most of the spit is privately owned above the mean high tide line and has been almost completely developed during the last 20 years with expensive single family dwellings. The spit has also been extensively reshaped on the inlet side and a sizable artificial lagoon has been created entirely within the spit.

Like most California beaches exposed to open ocean influence, the beach width on the Bolinas spit varies seasonally, narrowing in the winter due to storm erosion and widening again in the summer. The average seasonal variation is about 100 feet (Johnson, 1970). Unfortunately, however, since this figure is an average, extreme storm conditions can threaten the private homes, many of which are close to the beach. In 1977-78, nine homes were nearly undermined by erosion of the beach and adjacent low dunes during a combination of high wave conditions superimposed on high tides. Temporary sandbagging and placement of a Longard tube was undertaken and some rock revetment was later placed (Domurat, 1978: Moore, 1978).

Despite a proper concern for the houses, there is no particular threat to the barrier spit as a geological feature while it remains in state of dynamic equilibrium. No significant amount of new construction nor intensification of use is likely under the applicable governmental policies.

Morro Bay

Morro Bay is a shallow natural harbor located about 200 miles south of San Francisco. The lagoon, which has an area at high tide of about 3.2 square miles, is separated from the open ocean by a barrier spit about 4 miles long and 1,700 feet wide, and is ridged with both active modern dunes and heavily vegetated dunes of intermediate and ancient age. The primary sources of sand are sediments from the Chorro Creek and Los Osos Creek drainages which continue to slowly fill the inlet (Shepard and Wanless, 1971; Cooper, 1967).

The natural entrance to the lagoon has been greatly modified for small craft navigation. The entrance, which is at the north end of the harbor and skirts the north end of the spit, is in the lee of Morro Rock, a large granitic monolith which is connected to the mainland by a tombolo-like formation. Formerly, the rock was an island with a sand bar in its lee dividing two separate shallow channel entrances into the bay - around the north the south side of the rock, respectively.

Harbor improvements constructed in the early 1930's cut off the north channel. Because of continuing shoaling, two converging breakwater - jetties were constructed to protect the entrance, one from the south side of Morro Rock and another from the barrier spit. Shoaling of the entrance remains a problem, however; and an average of about 120,000 cubic yards per year of material must be removed to keep the channels at a depth of 16 feet. Sand moves both ways but the net drift appears to be to the north; most of the shoaling is due to littoral movement though some material does blow off the spit into the interior channels. Spoil disposal has generally been on adjacent beaches. The harbor improvements have resulted in an accretion north of Morro Rock and readjustment of the position of the tip of the barrier spit; however, in general, the barrier is in a state of dynamic equilibrium. The most notable natural change in recent times would appear to be continued dune building and advance of dunes into the tidal flats and shallow water behind the spit (Cooper, 1967). The tip of the spit adjacent to the entrance is open space which will be protected by the City of Morro Bay's Local Coastal Program; the balance of the spit is a protected State park. The entire spit is without road access and is otherwise undeveloped. Its continued preservation seems assured.

San Diego Bay

San Diego Bay (Figure 4) is an elongated, crescent-shaped embayment of variable width with a high tide area of about 16.6 square miles. It is separated from the Pacific by a narrow sand barrier which

FIG. 4: SAN DIEGO BAY

connects with Coronado Island and North Island adjacent to the bay entrance at the north end of the bay. The bay entrance, which is partly protected by the sheltering headland of Point Loma to the west, is self-scouring to a natural controlling depth of about 25 feet; but is maintained at a much greater depth (up to 42 feet) to allow deep draft access to the bay, which is one of the finest natural harbors in the world. Tidal scour has been assisted by construction of a training jetty, on the barrier side of the channel, completed in 1904. Dredging maintenance requirements are low.

The bay appears to be a drowned, possible faulted valley, and the barrier grew by northerly currents moving sand from the Tijuana River and Otay River deltas (Shepard and Wanless, 1971) to the south (continued supply has been from the Tijuana in recent times). The narrow part of the barrier, or strand, is about 7 miles long and in its natural state had a variable width of about 500-700 feet. The beach was backed by low-active dunes averaging about 10 feet high which tend to encroach into the bay locally widening the strand considerably (Inman, et al, 1974). Although occasionally breached during high wave conditions, the barrier has always been continuous in historic times (Hertlein and Grant, 1944; Herron, 1980). North Island and Coronado Island were joined into one in 1944 by hydraulic filling with dredge material; the combined "island" feature is about 3 miles long and 2 miles wide. Hydraulic filling continued apace in the area from about 1910 to the 1970's; the northern and eastern margins of the bay were greatly reshaped and the barrier was widened at several places. The period of greatest activity was in war years of the 1940's when the bay was deepened extensively for the Navy, generating large volumes of spoil; over 28 million cubic yards of excess sand was placed on the seaward side of the barrier between 1940-46 (with smaller fills since), greatly widening the beach (Inman, et al, 1974). Despite slope readjustments, beach recession, and littoral movement, some of this sand remains in the area.

The barrier (or Silver Strand as the narrow portion is known) is remarkable for the diversity of the land uses - both military and civilian. At the north is the North Island Naval Air Station, while Coronado is an incorporated city with residential, commercial structures, and a wide recreation beach; further south, a four-lane highway backs a wide beach and continues south along the barrier; naval housing areas behind the highway contrast with a reach with several multi-story condominiums on the seaward side of the highway, some close to the beach and protected with a rubble seawall; near the south end, a former widened dune area has been dredged and reshaped on the bay side to create a residential marina community. About two miles on the beach serve as popular State beach recreation area; several more miles are reserved for the Navy as an amphibious training area. Further to the south where the barrier widens to join the Tijuana and Otay floodplain, is a large Naval radio station. In the past, a railroad spur extended for the length of the barrier but has now been abandoned. Detailed engineering studies of a second bay entrance crossing the barrier have also been made but are presently inactive.

A sandy beach fronts the floodplain for several miles further south to the Mexican frontier, bordering the residential community of Imperial Beach, and is breached by the mouth of the Tijuana River. At the river mouth the beach consists of two narrow spits backed by a lagoon and marsh with an area of about 1.7 square miles, managed as a wildlife refuge.

In recent years, concern has grown about the maintenance of sand supply to the sand barrier primarily because the 1,730 square mile drainage of the Tijuana River, most of which is in Mexico, is now 72 percent controlled by dam construction (Phillips, et al, 1979). Previous to control, which was essentially completed at its current level about 1940, periodic floods supplied an annual average of about 700,000 cubic yards to Silver Strand beaches (Inman et al, 1974).

Littoral movements in the vicinity of the Tijuana River mouth are divided between north along the strand and south into Mexico. Physical evidence (movement of past fills, etc.) strongly supports a net northward movement along the strand. (Longshore transport calculations are not fully consistent in this matter although they indicate large transport to the north in the winter and to the south in summer.) It is known, however, that sand is moving along the barrier to the tip of North Island. Some of the material is accreting at the Zuniga Schoal area adjacent to the jetty along the east side of the entrance. Large amounts, however, are also moving into the entrance channel and are flushed offshore to a depositional area in depth of 50 to 110 feet. This latter volume is estimated at 2 million cubic yards per year, based on comparative bathymetric surveys (Inman, et al, 1974), but the estimate may need further investigation.

Therefore, since the natural sand source of the Tijuana River has been cut off, a continuing sand supply to balance losses at the northern end of barrier is no longer available and long-term recession of the beach can be expected without artificial protection or nourishment.

As might be expected, this problem should first become evident nearest the former source area. This hypothesis appears to be confirmed at Imperial Beach, just north of the Tijuana mouth, where erosion of the beach and damage to structures have occurred (U.S. Corps of Engineers, 1975). Due to the presence of a remnant delta of the Tijuana River, this area is a zone of wave energy convergence, which would tend toward increased erosion. The erosion has been countered by groin construction (which proved ineffective) and periodic beach nourishment; more permanent solutions such as an offshore submerged breakwater and fill are under consideration by the Corps of Engineers and the State of California.

Overall, the cutoff of sand from the Tijuana basin has resulted in a narrowing of the southern part of the barrier; however, at the north, the strand and North Island remain considerably widened over natural conditions due to past fills despite continued losses of material to Zuniga Shoal and the offshore sediment-deposition zone. Typical long-term changes, through the mid-1950's are as follows: Tijuana River and U.S. Naval Radio Station; average rate of change -2.3 feet per year (period of record 1889-1954); Silver Strand and North Island; average rate of change: +8.2 feet per year (period of record: 1856-1956). (May, et al, 1982)

Long-term stability of the barrier will require remedial human intervention and management. Artificial nourishment is a preferred solution as long as sources of fill can be readily obtained. A recent (1978) Corps of Engineers channel deepening in the bay provided an additional 6 million cubic yards of sand for Imperial Beach and the Silver Strand; although disposal of such dredging cannot be regarded as a permanent solution, significant amounts of suitable beach can be obtained in this way. Possible long-term solutions might involve, for example, recycling of sand now transported north to Zuniga Shoal and/or the adjacent offshore sediment sink (possibly with added structures in the area to accrete sand in the shoal for recycling before it is lost to the sediment sink). Alternatively, extensive "hard" structures - such as an artificial headland or series of headlands - might be considered for all or part of the entire littoral cell between the Tijuana River and the harbor entrance. However, this would be expensive and require a great deal of planning and investigation to minimize adverse effects on adjacent areas. In any case, improved monitoring of the wave climate and beach changes will be necessary so that future engineering decisions will be based on accurate knowledge of coastal processes. (Monitoring measures now being considered are discussed subsequently.)

Management jurisdiction for the barrier is divided between the Local Coastal Programs of San Diego County and the cities of San Diego, Coronado and Imperial Beach, as well as the Navy - whose upland jurisdiction is generally exempt from the California Coastal Plan. The application of current Coastal Act guidelines and Navy policy will prevent further encroachments on the beach side of the barrier. (For example, construction of additional large multi-story condominiums, similar to those noted above at Coronado, would probably not be allowed.) Preservation of the barrier spits which front the Tijuana River Marsh is also indicated under the applicable governmental policies.

In summary, human activities to date have greatly modified the barrier between the Tijuana River and the San Diego Bay entrance with considerable enlargements at the north, by dredged fills and beach nourishment, counterbalanced by upstream control of the Tijuana River, the likely principal sand supply to the strand. Recognizing the high level of development of the barrier, continued and intensified management will be necessary to protect its physical form and the multiple uses it sustains.

OTHER BARRIERS

Los Angeles Basin

A notable series of barrier features (Figure 5) exist along about 22 miles of the 30-mile long segment of coastline bordering the southern side of the Los Angeles Basin. The basin is essentially a large alluvial plain formed by deposits of sediment carried by the San Gabriel, Santa Ana and Los Angeles Rivers which, even in historical times, frequently changed location during flood periods and inundated vast areas (Shepard and Wanless, 1971). Until this century, six well-developed bay-mouth barriers breached by tidal inlets or associated with river mouths, and backed by about 25 square miles of marshlands, existed in this area (Speth, et al, 1976; Cooper, 1967).

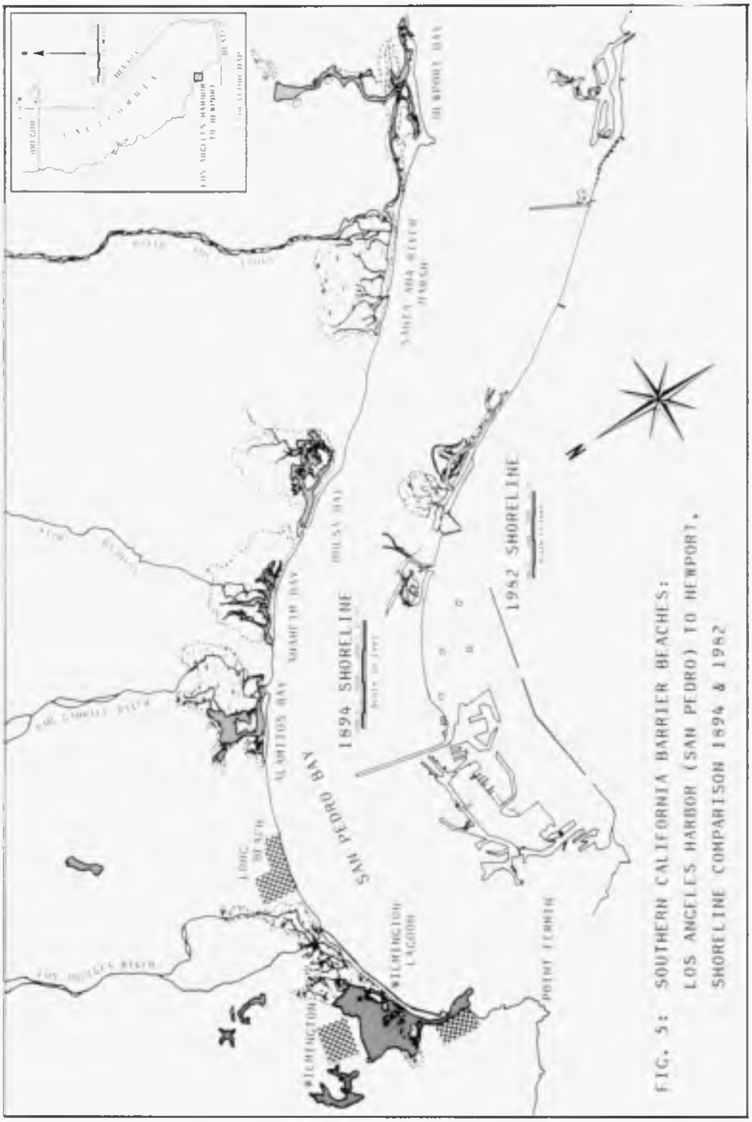

FIG. 5: SOUTHERN CALIFORNIA BARRIER BEACHES:
LOS ANGELES HARBOR (SAN PEDRO) TO NEWPORT,
SHORELINE COMPARISON 1894 & 1982

Today most of the area and the entire region has been utterly transformed by industrial and urban development. The Rattlesnake Island (or Terminal Island) barrier adjacent to the mouth of the Los Angeles River has become the center of a great port complex, almost totally reshaped and enlarged by dredging and filling, backed by intensive industrial, commercial and residential facilities, separated by the river by channelization and from the open ocean by three segments of Federal breakwater, with a total length of 8 miles (Parker, 1971)

Enlarged by fills, armored and bulkheaded, and in the wave shadow of the breakwater, the stability of the former natural barrier is no longer dependent on the usual coastal processes. The nearby barrier at Los Alamitos Bay adjacent to the mouth of the San Gabriel River lies just at the edge of the wave shadow of the breakwater; further downcoast are bay and river mouth barriers at Anaheim Bay, Bolsa Chica, Santa Ana River and Newport Bay. All of these areas (and intervening reaches) have suffered to some degree from beach erosion due to diminution of the sand supplied to the beach, notably at Surfside-Sunset (Anaheim Bay barrier) and at Newport which have residential areas close to the beach. Many factors have been advanced as contributing causes (Habel and Armstrong, 1977): diminished supply of sand from upland sources due to construction of dam and debris basins; sand and gravel mining from river channels; prolonged drought conditions in Southern California which act to limit supplies of sediment to the coast; jetty construction at Anaheim Bay; and losses to the submarine canyon at Newport Beach. In any event, it has been necessary to nourish most of the entire reach periodically with sands trucked from river beds or other inland sources, and more recently, dredged from an offshore borrow site. In addition, nine groins have been built along the west portion of the Newport barrier to retain beach fill.

Most of this coastline consists of sandy beaches, intensively used for public recreation and backed by a four-lane highway; the largest beach protection investments have been made in areas where residences and park facilities are on or close to the beach, in front of the highway or other roads. Under the Local Coastal Program policies of Orange County, and the cities of Seal Beach, Huntington Beach, and Newport Beach, the land uses should remain largely unchanged. Continued beach nourishment will probably be required.

Oceanside and Vicinity

A twenty-five mile segment of the coast southward from the vicinity of Oceanside, 65 miles south of Los Angeles Harbor, is of especial interest because of persistent beach and cliff erosion. The shoreline is bordered by elevated marine terraces fronted by generally narrow sandy beaches. At intervals, the terraces are interrupted by stream valleys containing brackish or saltwater lagoons and marshes which are separated from the ocean by narrow sand barriers. In all, nine such lagoon-marsh-barrier complexes are present in this reach.

Several communities lie along the marine terraces and border the lagoons. A particularly complicated situation exists at the town of Oceanside where breakwater-protected military and civilian small craft harbors, with a common entrance and landfills, have been constructed (1940's-1970's) in marshy areas behind barriers adjacent to the San Luis Rey and Santa Margarita Rivers. With seasonal reversals in littoral drift, shoaling problems have been severe in the entrance, which tends to act as a sand trap. Concurrently, severe erosion has occurred on the 2.2-mile reach of beach immediately south of the harbor in front of the city of Oceanside, stripping off sand, leaving cobbles on the beach and threatening roads and homes. This reach has required repeated nourishment with sand dredged from the small-craft harbor and truck-hauled from inland sources. Numerous studies and remedial actions have been undertaken by the U.S. Corps of Engineers regarding this problem.

There are also concerns about the effects of the harbor interrupting sand supplies to the beach. However, the entire 25-mile reach, which - as noted - is primarily bordered by cliffs (marine terraces), appears to be retreating. Primary causes cited include diminution of sand supply to the coast by upstream controls and due to the prolonged drought period (1948-1978): these causes being preparatory to episodic erosion of the cliffs during high wave conditions. Cliff erosion is also worsened by changes in groundwater and drainage of the bluffs due to urban development (Kuhn and Shepard, 1980).

The problems of most concern to the affected communities do not involve critical erosion on the barrier beaches which front the lagoons (barriers occupy about 8 miles of the 25-mile reach and several are protected by revetments, seawalls and periodic nourishment, Habel and Armstrong, 1977); but, the general problem has prompted initiation of a major coastal processes monitoring and investigative effort by the Corps of Engineers which emphasize this particular area. The study will be expanded to include the Orange County and San Diego coastlines between Dana Point near San Juan Capistrano, and the Mexican border. (This Congressionally-authorized study known as the CCSTA: Coast of California Storm & Tidal Action study, will ultimately include additional areas of California.) Monitoring and investigation of barrier features, though not separately distinguished as such, will be contained within the CCSTA, as part of studies of the larger coastline.

THE COAST OF CALIFORNIA STORM AND TIDAL ACTION STUDY (CCSTA)

Before concluding this paper it might be useful to discuss the CCSTA. The study plan is still being formulated by the Corps of Engineers, Los Angeles District; a multi-year program is envisioned initially emphasizing gathering of basic data, including expansion of an existing state-of-the-art wave gaging network, and recurring beach profiling and sediment sampling. Study planners are considering inclusion of field and office studies of wave hindcasting; quantification of sediment sources (streams, cliffs, coastal longshore drift, fills) and sediment sinks (submarine canyons and offshore deposition zones); historical shoreline changes; sea level fluctuations; and, climatic changes.

Data gathered would be analyzed in order to evaluate present conditions, predict impacts of proposed changes and aid in formulation of local and regional solutions.

Although, as noted, this overall plan is still being developed, data collection for the CCSTA and related program has already begun; the existing Corps of Engineers wave gaging network (Domurat and Pirie, 1980) is being expanded to include directional wave gages at additional locations in the San Diego region, and beach profiles which will ultimately cover 100 ranges over the 85-mile reach from Dana Point to Mexico.

One directional gage (Seymour and Higgins, 1978) is being planned for installation at Imperial Beach at the south end of the Silver Strand, and at least one other gage further north along the barrier is under consideration. If carried out, this would be an important step toward better quantification of coastal processes between the Mexican border and Zuniga shoal.

SUMMARY OBSERVATIONS AND CONCLUSIONS

In summary, though of secondary importance, barrier beach features are widespread in California. As indicated in the above case histories, most California barriers have been essentially stable in historic times. Those subject to erosion have been maintained in place by artificial beach nourishment or other protection. Although present management practices will probably continue to be satisfactory, human intervention with beach nourishment and structures may be necessary in some areas. However, such intensified solutions will have to be based on more complete data on coastal processes, in order to respond to tightened State and local coastal management policies.

As recognized by various observers, the coast of California is readily characterized as one of cliffs and bluffs; the cliffs commonly being elevated marine terraces (Kaufman and Pilkey, 1979; Shepard and Wanless, 1971). Barriers are less extensive in California than in many other areas due in part to lesser sediment supplies from restricted drainage areas. Still, as noted, a sizable portion of the California shore is bordered by barriers; and as case studies indicate, their protective functions can be quite important. Some of the barriers are small-scale features occurring at the mouths of streams which breach long reaches of coastal cliffs or mountains. Others are sizable features, often associated with larger geologic elements such as intermontane valleys or alluvial plains - the Los Angeles Basin is an example - which adjoin the coast. Of the barrier beaches examined: Humboldt, Bodega, Bolinas, Morro Bay (and the large majority of smaller barriers identified) have remained essentially stable throughout historic times, despite varying degrees of human activity. Southern California barriers between Los Angeles and Newport and at San Diego have generally been subjected to erosion by interruptions to sand supplies - in part because of urban development. However, the barriers - some of which are no longer recognizable, have either been stabilized by protective works or artificial sand nourishment. In the Oceanside area, erosion problems at the several barriers have been dealt with by localized protection; however, a more general condition of beach and episodic cliff retreat continues along a 25-mile reach.

The latter case, and that of the San Diego Bay barrier (whose sediment supply is now dependent on a dam-truncated watershed), give evidence that barriers are part of larger systems which should be better understood if intelligent coastal management is to be carried out. Regional studies of wave regimes, shoreline changes and related coastal and watershed processes are desirable to understand what is happening to the shore and to evaluate any prescribed actions, which might range from continuing current practices of incremental protection, through large-scale beach nourishment and engineered coastal stuctures.

Ultimately, some beaches and coastal barriers - especially in southern California - will need protection. Although artificial nourishment remains the favored technique, economic considerations may necessitate combining nourishment with structures to reduce losses of beach material. Certain barrier-associated coastal lagoons could also benefit from limited dredging to remove excessive sedimentation which threatens their continued existence. (This is, however, a controversial issue.)

This observer believes that State and local coastal plans, although strict, will prove flexible enough to allow necessary improvements, provided they are presented and justified on a rational and technically-sound basis. In this regard, expanded study, monitoring and evaluation of the impacts of coastal and related processes on barriers and other shoreline features such as those planned for the CSSTA study should prove useful.

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