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Headlands and Groins: Replicating Natural Systems

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ABSTRACT

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California is the most populous state in the nation, and 80 percent of its 35 million people now live within 50 km. of the coast. Beaches play a major role in the state's economy as recreational outlets and vacation destinations but also serve to buffer developed coastal bluffs and cliffs from direct wave attack. A reduction of beach sand supply has taken place over the past several decades due to a combination of dams on coastal streams, armoring of eroding seacliffs, mining of sand directly from river beds as well as the shoreline and the reduction in large sand contributions from coastal construction projects.

The most common historical response to both seasonal beach erosion and long-term shoreline retreat in California has been seawalls and rip-rap. In recent years beach nourishment has been advocated by local government and the tourist industry as a solution to shoreline erosion and beach losses. More recently, the concept of removing dams which no longer serve any useful purpose and have trapped large volumes of beach sand have begun to be seriously evaluated.

Groins have been successfully used in California to create, widen or stabilize beaches. Many of California's beaches exist because of natural littoral drift barriers such as headlands and a number owe their existence to artificial barriers such as groins, jetties and breakwaters. Groins mimic natural features and with appropriate planning, can be used more extensively to hold the sand on California's beaches in place, thereby increasing both shoreline protection and recreational areas at far less maintenance, cost and with less negative environmental impact than either armoring or artificial nourishment.

ADDITIONAL INDEX WORDS: *Groins, shoreline erosion, beach erosion.*

INTRODUCTION—THE PROBLEM

Everyone supports beaches and few would argue that to the degree that we can increase the amount of littoral materials or beach width, we are improving both shoreline protection and enhancing our recreational resources. The rush to the coast continues in the United States. Population growth rates tend to be highest in coastal states and increasing number of residents and tourists flock to the beaches for their vacations. In California alone, recreation and tourism along the coast are major economic engines, producing approximately $10 billion in revenues annually and supporting over 500,000 jobs. Much of this $10 billion is directly related to the state's beaches. While coastal populations and beach usage are increasing, there are concerns that beaches, particularly in southern California, are diminishing in size. This is due to acombination of the reduction of sand input from 1) dammed rivers and streams, and from 2) the armoring of eroding seacliffs, as well as sand mining from beaches and stream beds, and the termination of the large harbor/marina and other coastal dredging and construction projects of the past half century with the associated placement of millions of cubic meters of sand onto the beaches of southern California (FLICK, 1993).

There are essentially two ways to increase the extent or width of beaches: 1) increase the amount of sand reaching the shoreline or on the beach, or 2) reduce littoral transport or trap the sand such that more of it stays on the beach. Artificial beach nourishment can improve the situation, at least over the short term. However, there are a number of environmental as well as long-term sand availability, costs and life-span issues associated with this approach that have been active topics of discussion and controversy for over a decade.

Another approach that has been used in the past but which has created down-drift impacts or other side effects has been the emplacement of groins. Particularly in southern California, groin fields have been used effectively to stabilize and widen beaches at Ventura, Santa Monica and Newport Beach (Figure 1). While there are a number of crit-

Figure 1. A groin field has been used effectively to stabilize and widen the beach at Ventura, California (1989).

ically important design considerations and precautions (location, height, length, and spacing of groins, for example), as well as the sand volumes needed to fully charge groins following construction, groins basically mimic natural systems (Figure 2).

CALIFORNIA'S CENTRAL COAST—THE IMPORTANCE OF LITTORAL DRIFT BARRIERS

Many of California's beaches exist because of natural littoral drift barriers such as headlands

Figure 2. A resistant siltstone bed outcrops in the surf zone and forms a natural groin trapping upcoast sand along the coast between Santa Cruz and Half Moon Bay (1972).

Figure 3. Resistant headlands and Laguna Beach in southern California have trapped the southward flowing littoral drift forming large pocket beaches (1989).

and points (Figure 3). EVERTS and ELDON (2000) recently reported that over 75% of the beaches in southern California are retained by structures:

"Two-thirds of those structures are headlands, surface-piercing or submerged reefs, near-coast submarine canyons, rock stream deltas, and various types of irregular bathymetry. The remaining third are jetties, groins, and shore-parallel and shore-normal breakwaters.

Figure 4. A large pocket beach has formed upcoast of a resistant headland at the mouth of a stream (Scott Creek) north of Santa Cruz (1984).

Figure 5. A composite image of Monterey Bay showing Monterey submarine canyon which heads at Moss Landing in the center of the bay.

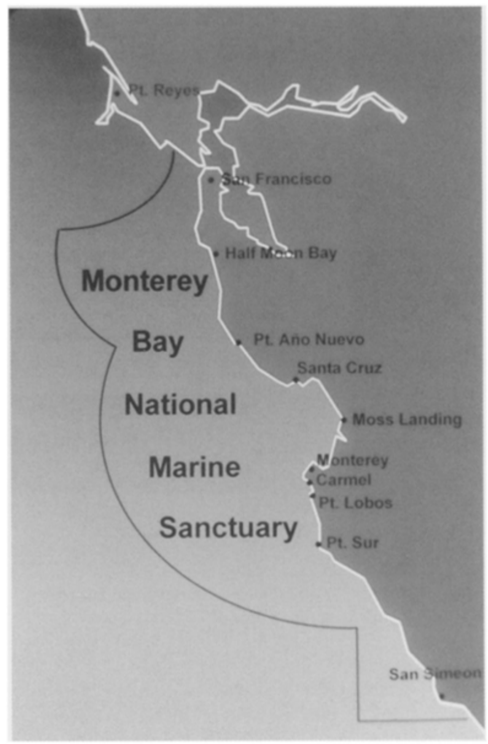

Figure 6. Location map for the central California coast showing major cities.

By regulating the breaking wave height, the angle waves make with the shoreline, and the path sediment takes as it moves along the coast, beach-retention structures promote wider and more stable beaches than would otherwise exist. Performance and adverse impacts vary from place to place depending upon a complex interdependence of the type and size of the retention structure, the way in which it regulates the longshore component of energy flux, and local orientation of the coast. At dynamic equilibrium, the net quantity of sediment transported along a retained beach is in balance with the supply reaching it".

The coast of central California is similar to that of southern California in that many of the beaches exist because of either natural or artificial littoral drift barriers. The dominant direction of littoral drift in this region is from north to south and many beaches have formed where there are barriers or obstructions to downcoast or southerly transport. Along the relatively undeveloped coast between San Francisco and Monterey Bay, many of the localized beaches have formed in the embayments at the mouths of the many small coastal streams, where resistant downdrift headlands exist. Much of this coastline consists of relatively homogeneous sedimentary rocks (sandstones or mudstones) such that beach formation is a result of sand trapped in the streamcut embayments rather than particularly resistant headlands. Beach size depends upon the shape (length and width) of the embayment and/or the seaward extent of the headlands (Figure 4).

The most extensive reach of sandy beach along the central coast of California is within Monterey Bay where a continuous wide sandy beach 48 km in length exists between the headlands at Pt. San-

Figure 7. The jetties of the Santa Cruz small craft harbor and the upcoast beach (Seabright Beach) that has formed from trapping of littoral drift (1997).

ta Cruz on the north and at Pt. Pinos on the south. Central Monterey Bay is a structural depression, in large part occupied by the drainages of the large Salinas and Pajaro rivers, and is backed by low bluffs or dunes. Monterey Bay could be considered as a very large pocket beach, with a major sink, Monterey submarine canyon, in the geographic center of the bay (Figure 5). Sand mining of the beaches of southern Monterey Bay was a large historical sink as well. By virtue of the extensive and accessible beaches of Monterey Bay, this area has become a major recreational area for the over eight million people living in the Santa Clara/Silicon Valley and greater San Francisco Bay areas as well as visitors form the Central Valley.

There are 150 km of shoreline between the Golden Gate and the northern edge of Monterey Bay and 45 km of this reach or 30% consists of beaches, pocket beaches in many cases. This is similar to the state as a whole, where 28% of the coastline consists of pocket beaches, typically bounded by rocky headlands and often formed at the mouths of coastal rivers and streams.

This stretch of the central coast has been altered to some degree by human activity although there are only a few large engineering structures. From north to south these include the Half Moon Bay breakwater, the jetties of the Santa Cruz small craft harbor, the groin at Capitola Beach, the jetties of the Moss Landing harbor, and the breakwater at the Monterey harbor (Figure 6). Because of the locations and physical setting of these structures within their littoral cells, and the direction and magnitude of littoral drift, only two of these structures impound significant sand, the jetties at Santa Cruz and the groin at Capitola (Figures 7 and 8).

The jetties at the entrance to the Santa Cruz small craft harbor extend well into the surf zone and were built at the downcoast end of a high littoral drift cell between 1963 and 1965 (GRIGGS, 1986). They had a significant impact on littoral transport immediately following construction as large volumes of sand began to accumulate upcoast while downcoast beaches were initially starved (GRIGGS and JOHNSON, 1976). Annual dredging began as soon as the harbor was completed and continues at present-day rates of about 150,000–175,000 m^3/year. It took about 15 years and several million cubic meters of littoral sand to fully charge the upcoast beach but equilibrium was essentially reached in 1980 (Figure 7). Annual dredging removes sand from the entrance channel and inner harbor and discharges it onto the downcoast beaches where it re-enters the littoral system and continues southeast to the Monterey Submarine Canyon where it exits the cell (Figure 5). While downcoast beaches were impacted during

Figure 8. The groin at Capitola has created a nearly permanent year-round beach (1997).

the first 15 years following construction, it is believed that littoral drift is now essentially in equilibrium as the sand dredged from the entrance channel is put back into the littoral drift system on a regular basis (GRIGGS and JOHNSON, 1976).

A natural headland immediately upcoast from the harbor, San Lorenzo Point, was historically the primary reason for the existence of the main Santa Cruz city beach (Figure 9). Because of the wide summer beach that formed upcoast of this natural groin, this site became the center of a tourist-based recreational area that has flourished for over a century. The Santa Cruz Main Beach and Boardwalk presently attract some 3,000,000 visitors annually and play a major role in the city's economy. This area was the main city beach until the completion of the harbor jetties at which time the upcoast beach (Seabright Beach) widened to as much as 200 meters and became a second intensively used recreational area. As the beach upcoast of the harbor continued to widen throughout the 1970's and into the early 1980's, it eventually extended seaward of the natural groin and the entire beach widened from the jetty for a distance of 2000 m upcoast (Figure 10). Although not its intent, the harbor's upcoast jetty has served as an effective littoral trap or groin and been responsible for the formation of a large permanent city beach which provides recreational space for thousands of residents and visitors (Seabright Beach) as well as expanding an existing beach (Main Beach) that owed its original existence to a natural groin.

An additional benefit of the beach that formed upcoast of the harbor's west jetty was the permanent protection of the previously eroding bluffs (Figures 11 and 12). A city street that had been undermined and partially destroyed and a number of threatened residences are now protected year-round by a beach up to 200 m wide (Figure 13).

Proceeding downcoast, there are two adjacent intensively used stretches of sandy beach, not as wide as the beaches just discussed, and both have formed upcoast of headlands, Black Point and Soquel Point (Figure 10). The combination of three natural groins and the west jetty at the Santa Cruz Small Craft Harbor have created over 4 km of nearly year-round beach for the region's residents and visitors to enjoy and that also provides an important buffer for the bluffs from direct wave attack.

About 6 km downcoast of the Santa Cruz Harbor jetties is the small beach community of Capitola. While Capitola initially lost their pocket beach due to sand impoundment following harbor construction upoast (GRIGGS and JOHNSON, 1976), because of the community's dependence on the beach-going visitors, they constructed a groin and then backfilled it with approximately 45,000 m^3 of sand in 1969–70. While the beach does thin every winter and disappear completely during heavy El Nino winters (Figure 14), as it did prior to groin construction, it traps enough littoral sand to form a wide public beach each summer. Thus the groin has been a successful solution to Capitola's beach disappearance problems and was accomplished with backfilling such that it had little significant impact downcoast. The approximately 1 km stretch of high cliffs immediately downcoast of Capitola are oriented almost northeast-southwest such that littoral drift doesn't allow a permanent beach to form. As a result, the unprotected cliffs have been eroding at 20–40 cm/yr for the past century, regardless of the existence of a beach or groin at Capitola.

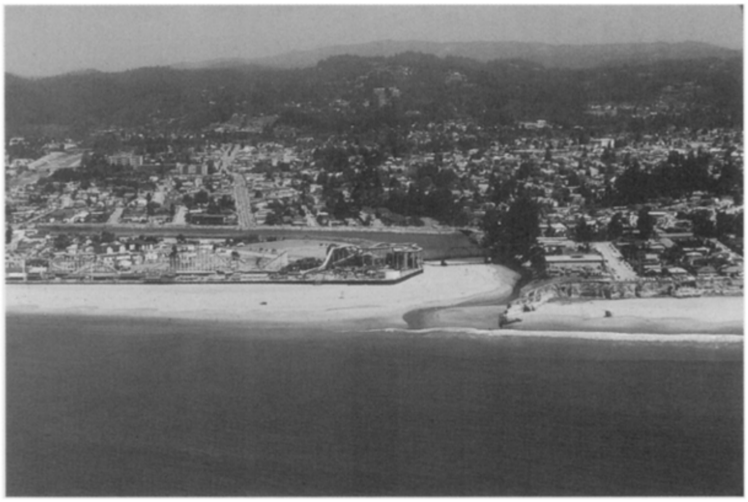

Figure 9. San Lorenzo Point (to the right of the river mouth), a natural groin which has created a wide, permanent upcoast beach (Main Beach in Santa Cruz-1997).

CONSIDERATIONS FOR THE FUTURE

California and most of the world's coasts experience two types of shoreline or coastal erosion. One is the predictable seasonal beach scour or erosion that accompanies the arrival of high energy winter storm waves. While there are annual variations in the extent of winter beach erosion and subsequent summer accretion, if the littoral sediment inputs to the system and sediment outputs from the system are more or less in equilibrium, these seasonal changes will average out over time. Even the severe beach scour that accompanied the large ENSO events of the recent past along the central California coast was almost totally recovered by the following summer (BROWN, 2000). Even though the beach recovers each spring and summer, there are many structures in central and southern California that have been built on the beach that are threatened or have been damaged by severe winter beach scour (Figure 15). However, where beaches are very wide, for example, much of inner Monterey bay, they can usually accommodate all but the most severe seasonal changes in beach width without threats to the bluffs or dunes backing the beach.

The second type of coastal erosion is the net erosion or landward migration of the shoreline, whether dunes, low bluffs or high cliffs. In contrast to seasonal beach scour, these losses are not recoverable. Past regional assessments have concluded that 86% or about 1500 km of California's coast is undergoing net retreat during recent time (U.S. ARMY CORPS OF ENGINEERS, 1971). If we were to look at the long-term, however, the entire coast of California has been in retreat for the past 18–20,000 years at the time the last Ice Age ended and sea level began to rise from an elevation ~130 m below present.

For many reasons, oceanfront property on coastal bluffs or cliffs is among the most valuable in the state of California, even though all of this property should probably be considered to have a finite half-life. That half-life is dependent upon both extrinsic factors (the rate of sea level rise and maximum elevation that future sea levels will ultimately reach) and also intrinsic factors (the materials that make up the cliffs or bluffs and their resistance to erosion).

Historically there have been several different responses available to either property owners or government entities owning developed property that is threatened by either of these two coastal erosion processes (GRIGGS, PEPPER and JORDAN, 1992 and GRIGGS, 1999). These include:

- non-response:development abandonment
- retreat or relocation of structures

Figure 10. Three headlands and a jetty are responsible for creating the main beaches for the city of Santa Cruz. From top to bottom, Soquel Point, Blacks Point, the jetty of the Santa Cruz small craft harbor, and San Lorenzo Point. Note how the sand trapped by the jetty has extended the upcoast beach further seaward of the natural groin (1997).

- armor or hard protection strategies
- soft protection strategies (sand nourishment or replenishment)

The first two approaches are straightforward but have not been the solutions generally taken in the past. There are many sites where roads and other public structures have been abandoned (Figure 16) and also an increasing number of instances where structures have been relocated inland, perhaps the most recent and best publicized being the $9 million relocation of the Cape Hatteras lighthouse by the National Park Service.

Armor or hardening of the shoreline has been the most common solution to shoreline erosion problems in California over the past 50 to 75 years (GRIGGS, 1999). At the present time, approximately 172 km or 10% of the state's entire coastline has been armored. In contrast to the property owners' concerns about costs, lifespan and effectiveness of specific protection structures, considerable public opposition has arisen in recent years concerning proposals for new seawalls and revetments because of perceived direct and indirect impacts of these structures. Many of the concerns, including aesthetic or visual impacts, restrictions on beach access, reduction of sand supply from previously eroding bluffs, and loss of beach beneath the riprap or seawall, revolve around the issue of to what degree should private property owners be allowed to impact public beaches as they attempt to protect their own property. Or, in the case of government funded projects, how much taxpayer money should be spent in attempts to stabilize the position of an eroding coastline, albeit a very valuable coastline?

Beach nourishment or replenishment has emerged in the last decade as an appealing "soft" approach to dealing with the problems of shoreline erosion. On the surface, this strategy represents an attractive compromise between the extremes of abandoning the shoreline on the one hand and armoring it with concrete or rocks on the other. The beach is nourished with sand from either an offshore or inland source. The goal is to increase the width of the beach so that more sand is available as a buffer to wave attack and also for recreational use. A wider beach could significantly reduce the potential impacts of seasonal beach scour and also slow long-term shoreline erosion.

Although beach nourishment may offer significant benefits, it is a costly proposition with a number of limitations or concerns. Along the coast of California most littoral cells are relatively large (10s to 100s of km in length) and most littoral drift rates are very high (150,000–750,000 m^3/yr), such that the life span of the sand added to a particular beach is likely to be fairly short. A relatively recent study of west coast nourishment projects found that 18% survived less than a year, 55% lasted only 1–5 years, and only 27% survived over 5 years (LEONARD *et al.,* 1990). A number of issues and questions have been raised at the national level, however, as to what constitutes a successful nourishment project.

At offshore dredging costs of \$3–4/m^3, placing 300,000 m^3 annually on a beach from adjacent offshore sources (were sand available of the appropriate grain size) would cost \$900,000 to \$1,200,000/yr. Inland sources of sand would have significantly higher costs as well as the environmental impacts of removal, transport, and beach

Figure 11. Seabright Beach (~1900) looking west towards San Lorenzo Point. Prior to harbor construction there was only a narrow beach in this area.

dispersal. The long-term availability of adequate volumes of compatible or acceptable sand, life span of a nourished beach, and funding for projects, are unresolved issues in California and have been stumbling blocks for most nourishment proposals to date. While considerable nourishment has taken place historically in southern California, for the most part nearly all of this has been as a by-product of the dredging of harbors, marinas or other construction projects rather than a stand-alone nourishment program, and therefore costs, payment, sand sources, and life span were not issues that had to be resolved.

In southern California, much of the littoral sand supply reduction and apparent beach narrowing has been due to the hardening of the channels and damming of the streams which originally supplied most of the region's beach sand. Many of the dams and reservoirs no longer serve their intended purposes because storage volume for water and flood control capacity is filled with sand (WILLIS, 2000). Sand is present in the system, it's just in the wrong place. Before vast amount of money are invested in searching for new sand supplies and in short-term plans to nourish beaches, we need to look at the natural fluvial sources and transport mechanisms again and consider approaches to return these coastal watersheds to their original status as natural, long-term, cost-effective sources of beach sand. Several dams have already been targeted for removal and exploratory work is underway to assess the feasibility and environmental impacts, and also to evaluate different approaches to dam removal and sediment delivery to the shoreline (CAPELLI, 2000).

Another approach, which like removing a dam, is a solution that can be viewed as reverting or returning to a natural process, is that of constructing groins. Rather than focusing all of our efforts on either finding new sources of sand or returning natural sand flow to the coast through dam removal (which is an objective we need to continue to vigorously pursue, but which is a process that will not be quick or easy to accomplish for many reasons), I believe we should look carefully at the strategic use of groins.

Groins have been successfully used at a limited number of locations in California, but have often been lumped with the much larger breakwaters and jetties as coastal engineering structures that have had major secondary or negative downdrift effects. Without question, the jetties and breakwaters that have created many of California's ports and harbors have had major impacts on littoral drift. As a result of this connection, groins have fallen into general disfavor in recent years and aren't often considered as approaches to building or stabilizing beaches. In contrast to jetties

Figure 12. Seabright Beach 1975 (same location as Figure 11), ten years after Santa Cruz small craft harbor construction showing the wide permanent year-round beach that has formed.

and breakwaters that may be many hundreds or thousands of meters in length, and which often necessitate expensive annual dredging to maintain the littoral drift system (GRIGGS, 1986), groins can be of variable length and height and do not require maintenance or dredging. While there are a number of important design considerations and precautions associated with groins, they basically mimic natural systems and become artificial headlands (Figure 8). As such, they trap sand and either create beaches where they previously did not exist or serve to widen existing beaches. In either case,

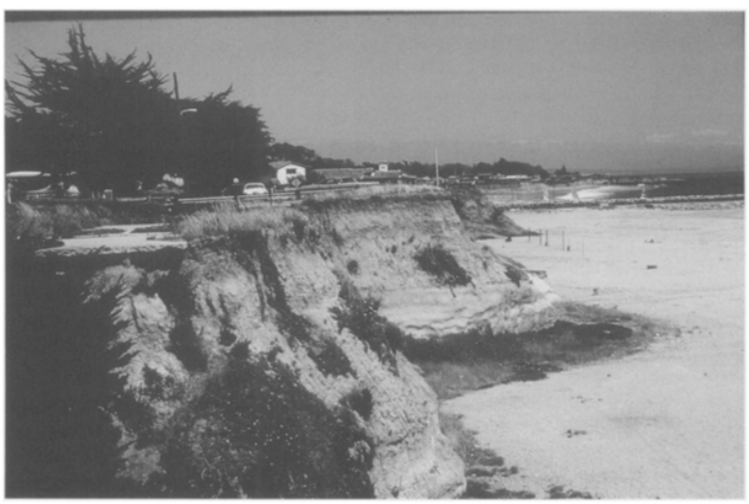

Figure 13. Remnants of the former ocean front street above Seabright Beach that was eroded prior to the construction of the harbor jetties at Santa Cruz. Note jetties in the background.

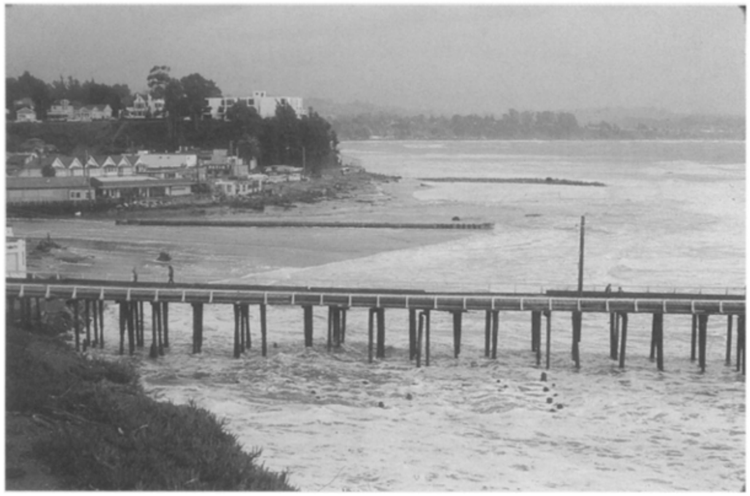

Figure 14. Capitola Beach undergoing severe winter scour. Groin is in background with drainage pipe to control summer lagoon overflow in middle distance.

they have the potential to reduce the problems or impacts of either seasonal beach erosion or slow long-term shoreline erosion.

As EVERTS and ELDON (2000) have recently pointed out, over 75% of southern California's beaches exist because of natural, and in some cases manmade, littoral drift barriers such as headlands or obstructions. There are many other specific locations in central and southern California where either acute beach erosion or cliff erosion

Figure 15. Severe El Nino related beach scour in the winter of 1982–83 at Rio Del Mar led to undermining of piling foundations and collapse of beach level homes.

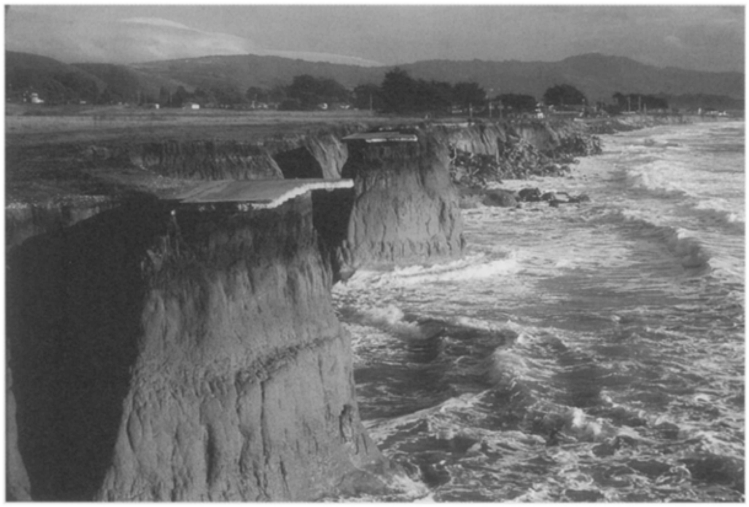

Figure 16. Severe bluff erosion south of the Half Moon Bay breakwater led to loss of oceanfront road and sewer line.

problems exist, where groins could be built to create wide protective beaches (Figure 17). This would provide for an additional buffer in areas of either beach or bluff erosion, would furnish additional access and recreational area, and eliminate the need to armor the shoreline, or provide long-term and consequently expensive annual nourishment. At present, many hundreds of thousands of cubic meters of sand leave the beaches of California each year and flow into the submarine canyons

Figure 17. Area of low eroding cliffs between Santa Cruz and Capitola where a seawall is being contemplated. This appears to be an appropriate area for groin emplacement that would form a beach that would both halt bluff erosion and provide recreational area (1989).

at the downdrift end of each littoral cell. To the degree that we can keep more of that sand on the shoreline, for longer periods of time, we provide significant benefits to the human occupancy of the California shoreline.

There are a number of considerations that need to be kept in mind in any efforts to employ groins to selectively widen beaches, however:

Appropriate Location

An important starting point for groin planning, the location needs to be an area of dominantly unidirectional, relatively high annual littoral drift rate so that there is enough sand in the system each year to recharge the groins following winter scour and beach erosion. For most of the California coastline, this is not a constraint.

Length and Spacing of Groins

The size, spacing and configuration of groins, is partially a design issue dependent on dominant direction of wave approach, but also dependent upon the extent of any existing beach and how much additional beach width is desirable. Groins have a number of advantages. They can be built incrementally such that an existing groin can be extended further offshore if a wider beach is desired, or additional groins can be built alongshore to expand the beach area initially created. Depending upon the type of groin built, they can also be relatively inexpensive to construct and relatively easy to remove if desired at some later date.

Recharging the Groins Following Construction

This issue is critical and regardless of the annual rate of littoral drift, experience indicates that to reduce the issue of future concerns or impacts, the groin or groin field should be initially fully charged. By providing the sand necessary to completely charge or fill the groins at the onset, the littoral system has been compensated for the sand necessary to build the new beach. In subsequent years, the downcoast beaches will either receive the sand from the groin field from winter scour as new littoral sand moves into the reach from upcoast, or the sand held by the groins will remain in place and upcoast littoral drift will move along the shoreface of the new shoreline and will nourish the downcoast beaches. In either case, the system has been compensated.

Liability Removal

One recurring problem, which may be one of the most difficult to resolve, is that of future public liability. In California, lawsuits are frequently filed against local or state governments due to diving accidents and injuries in the surf zone of public beaches. Legislation is now in place, however, which eliminates public liability if an injury is a result of a natural occurrence. If for example, as has frequently happened, a person is seriously injured while body surfing at a natural beach, the local government entity can not be held liable. If however, an accident can be shown to have been due to a human alteration of an otherwise natural system, for example, a person dives off a groin on a public beach and is seriously injured, then the immunity doesn't exist. This doesn't necessarily mean the local entity is liable, but the door is open to enter the courtroom. Appropriate signage and a groin design to minimize the risk of injury are precautions that can lower the legal exposure but probably not eliminate it.

CONCLUDING THOUGHTS

For each of the options available to reduce the impacts of either beach erosion or shoreline retreat, there are short- and long-term costs and benefits that need to be considered. Its time to think in terms of long-term solutions and responses that either attempt to return systems to their natural functioning (such as removing dysfunctional dams and allowing sand to move downstream and anadromous fish to migrate upstream) or mimic natural systems or processes (such as constructing artificial headlands or groins). In the long run, it appears as those these approaches will be more economical and have less environmental impact.

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