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# CALIFORNIA'S RETREATING COASTLINE: WHERE DO WE GO FROM HERE?

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## 1. INTRODUCTION

California's coastline is approaching a crisis point, which has resulted from a combination of natural processes and cycles, combined with human intervention and population growth. The coast of California has been retreating in response to a continuous sea level rise over the past 18,000 years. While sea level rise rates have slowed over the last 3000-5000 years, there is no indication that this will subside in the near future; in fact, most scientists predict an increase in this rate. Of more immediate concern to California, however, are the impacts of severe El Niño events, specifically, large storm waves coincident with elevated sea levels as we experienced in 1982-83 and 1997-98. The beginning of a two-decade long period of more frequent ENSO events in 1978 altered our perception of coastal hazards in California (Figure 1). Most oceanfront residents and government agencies that have some shoreline responsibility have responded to the damage and losses with proposals for reconstruction or repair, seawalls or revetments, or requests for beach nourishment projects.

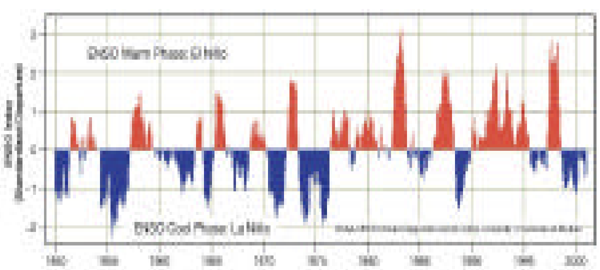

*Figure 1. ENSO index 1950-1990.*

California's population reached 36 million in 2004, a doubling since 1965. The state's coastal property values are at all time highs, with houses literally on the sand for sale in the $5-$10 million range (Figure 2). While the entire state's coastline has migrated eastward 5-25 km over the past 15,000 years, because of the investment and high property values, significant public and private funds have been expended in efforts to slow or halt any additional retreat. Our future options are limited, however, and they need to be both sustainable and cost-effective over the long-term. The lack of any certainty in the maximum elevation that sea level will ultimately reach, or knowledge of when this will occur, make it very difficult to develop sensible and balanced long-term strategies for responding to coastal retreat.

Present engineering and regulatory attempts to mitigate the problems associated with coastal retreat are clearly inadequate, because land, buildings, and infrastructure continue to be lost. There is an active controversy regarding the best approach to a resolution of these problems in areas of existing development: "Passive" solutions that advocate relinquishing threatened land to the advancing sea; "soft" solutions, such as replenishing or nourishing protective beaches; and "hard" engineering solutions, such as constructing seawalls or revetments.

*Figure 2. New house built on the sand with an asking price of $10,000,000.*

## 2. PASSIVE SOLUTIONS: RELOCATE OR RETREAT

Relocating or removal of oceanfront structures or infrastructure is being given increasing consideration in some locations. Where erosion rates are high, where a structure or infrastructure is close to the cliff or bluff edge, and where other approaches are infeasible, this may be the only solution. Where a parcel is large enough, a threatened structure can be moved landward on the same parcel, depending upon long-term erosion rates and the nature, size and condition of the structure, in order to extend its lifetime. Examples of comparative costs of relocation and reconstruction compared to protection (Griggs, 1986, 1995; Smith, 1983) indicate, that in the long term, relocation may be far less expensive. It is likely that this option has not been

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seriously considered by most threatened property owners, simply because of a desire to protect their home, property and view at any cost. There are an increasing number of sites, particularly on hurricane-damaged properties on the barrier islands of the South Atlantic coast of the US, where there are no other feasible options. As permits for seawalls become increasingly more difficult to obtain, this option may be pursued more frequently in places like California.

## 3. SOFT SOLUTIONS: BEACH NOURISHMENT

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 presents an attractive compromise to the extremes of abandoning the shoreline on the one hand, and armoring it with concrete or rock on the other. The beach is nourished with sand from either an offshore or inland source, with the goal of increasing the width of the beach so that more sand is available as a buffer to wave attack and also for recreational use

Although beach nourishment has the potential to 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, simply because the prevailing waves will immediately begin to move the sand alongshore. A number of issues and questions have been raised, however, as to what constitutes a successful nourishment project.

The first major beach nourishment project in California, carried out solely for the purpose of widening beaches, was completed in San Diego County in 2001. About 1,500,000 $m^3$ of sand was dredged from six offshore sites and pumped onto 12 different northern San Diego County beaches. The total cost was $17.5 million, or $11.67/$m^3$. Most of the sand was transported either downcoast or offshore during the first winter although one of the 12 sites retained sand for a year or so longer.

Inland sources of sand will have significantly higher costs (recent quotes in the Monterey Bay area were over $28/$m^3$), as well as the environmental impacts of quarrying, transport, and beach dispersal. Beach nourishment one dump truck at a time is not only expensive but also may not be a practical approach to arresting shoreline erosion. Nourishment was proposed recently as one approach to be analyzed for protecting a large condominium complex in southern Monterey Bay where the shoreline has been retreating at an average rate of about 35 cm/yr. The recommendation was for ~240,000 $yds^3$ of sand which would build a berm ~3000 feet long and 100 feet wide. This is equivalent to ~ 24,000 single 10 $yd^3$ dump trucks. If these trucks were used for hauling and the nourishment took place 5 days a week and 8 hours a day, and it was possible to have a truck dump a load of sand every 5 minutes, it would require 250 days or it would have to be done year round, which isn't practical. In the winter months beach access would be difficult and the sand would rapidly be removed; in the summer months the visitors and tourists want to enjoy the beach. It is simply not practical or feasible to maintain this rate of sand transport, dumping and spreading on the beach year around. Total costs of just obtaining and delivering this volume of sand would be about $5,500,000, making delivery from terrestrial sources a prohibitively expensive proposition.

The long-term availability of adequate volumes of appropriately sized sand, the life span of a nourished beach, and who pays for the project are unresolved issues in California, which have been stumbling blocks for most nourishment proposals. 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 coastal construction projects rather than a stand alone nourishment program, and therefore costs, payment, sand sources, etc. were not issues which had to be resolved.

The federal government has spent an average of $44 million annually (in 2004 dollars) for shore protection and restoration projects over the past 40 years, including a large number of mid- and south Atlantic shoreline nourishment projects; this practice, however, is under increasing federal budget scrutiny and has been targeted for significant reduction or elimination as the federal government attempts to deal with an increasing budget deficit.

## 4. HARD SOLUTIONS: SEAWALLS OR REVETMENTS

Over the past 50 years, the typical response to coastal hazards in California has been the construction of seawalls and revetments intended to protect eroding or wave-impacted coastlines. The 176 km of state shoreline, now armored, 10% of its total length, is testimony to this approach. Expectedly, the percentage of coastline armored is greater in the more densely populated southern California cities and counties than in the less developed central and northern portion of the state. Thirty-three percent of the coastlines of Ventura, Los Angeles, Orange and San Diego counties have now been armored. Protective structures have usually been built only after existing coastline development has been threatened. Rarely did a protection strategy precede development. Interestingly, however, despite a statewide Coastal Act and a statewide agency (California Coastal Commission), which deals with coastal development, policies within different municipalities on oceanfront construction vary widely (Griggs, Pepper and Jordan, 1992). There are local governments which require protective structures as a conditions for development, for example, and others which require 50 to 100 years of property life, based on long-term erosion rates, without any armor or protection, before a new dwelling can be constructed.

Protective structures can vary considerably in their cost, size, effectiveness, lifespan and impacts (Fulton-Bennett and Griggs, 1985). At one extreme, slabs of broken concrete in the past were dumped at the base of the cliffs in an attempt to reduce wave impact. Most low-budget, unengineered efforts of this sort have been relatively ineffective or very short lived, often lasting only a few years at most. At the other extreme are large, expensive, carefully engineered concrete seawalls, such as the O'Shaughnessy seawall along Ocean Beach in San Francisco, which has functioned effectively for 75 years (Figure 3). Costs for engineered coastal protection structures built over the past 15 years along the central California coast ranges today from perhaps $6000/m at the low end to over $25,000/m.

***Figure 3. The O'Shaughnessy seawall along Ocean Beach in San Francisco was built in 1928.***

Spending large amounts of money on the installation of a coastal protection structure does not guarantee long-term protection for home and property. The degree of exposure to wave attack, the foundation materials, as well as the specific design, construction and materials will all influence the life span and effectiveness of a structure. During prolonged or repeated wave attack under high tide conditions, such as that which occurred during the ENSO winters of 1983 and 1997-98, protective structures which may have survived for many years can fail virtually overnight.

Whether rock revetments, concrete seawalls or timber bulkheads, these protective structures have historically failed by scour or undermining, outflanking, overtopping, or simply battering or wave impact or a combination of these. In a study along the central coast of California (Fulton-Bennett and Griggs, 1985), of the three major types of protection, concrete seawalls have been the most successful in reducing erosion and property damage, and have been the most durable over the long term. Concrete, in and of itself, however, does not guarantee survival (Figure 4). Revetments typically fared less well than concrete walls, but better than wooden walls. The success of a revetment is a function of the foundation on which it is placed, the size, slope and height of the rock, and the internal layering. Wooden walls have been the least successful in preventing erosion and damage, and most are easily damaged during severe storms (Figure 5).

In contrast to the oceanfront homeowner's concern for the life span or effectiveness of a coastal protection structure, considerable opposition has arisen in recent years around proposals for new seawalls or revetments because of the perceived direct or indirect impacts of these structures. Many of these concerns, including aesthetic or visual impacts, restrictions on beach access, reduction of sand supply from previously eroding bluffs, loss of the 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's money should be spent in efforts to stabilize the position of an otherwise eroding coastline.

***Figure 4. Failure of a seawall in northern Monterey Bay due to loss of supporting fill behind the wall.***

***Figure 5. Failure of timber bulkhead at Seacliff State Beach due to wave and log impact.***

#### *4.1 Visual Impacts*

Any armoring structure built to protect either cliff, bluff, dune or back beach development has some aesthetic impacts (Figure 6). Whether a seawall, bulkhead, revetment or some other form of stabilization or protection, there is a visual impact, which can be much greater to the beach user or general public than to the owner of the property being protected. The visual impact of coastal armor is probably the issue that concerns members of the public the most. Far more attention today is being focused on visual impacts than was the case in the past when almost anything was dumped on the beach in an attempt to slow cliff retreat.

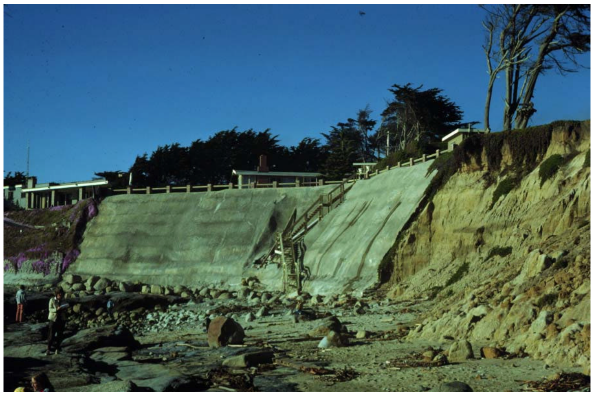

***Figure 6. Most coastal protection structures built in the past have some significant visual impact.***

One relatively recent approach in California has been the use of gunnite, which is colored and textured to match the native rock in the cliffs, much like the rock constructed for zoo exhibits. Colored and textured gunnite or soil-nail walls have been used to stabilize highway road cuts, but only recently has this approach been applied to coastal protection projects as a way to mitigate the visual impacts. These cliff stabilization projects usually involve first anchoring soil nails or tie backs into the bluff materials, and then constructing a steel reinforcing rod frame that mimics the shape of the existing bluff. This mesh is then covered with about 30 cm of gunnite, followed by a second 30 cm layer, which is textured and colored to match the adjacent rock (Figure 7). Further improving on this approach are recent examples of taking molds or peels of the adjacent existing rock, which can be used to create a concrete surface texture that looks indistinguishable from the original or native cliff materials (Figures 8). Concrete, if well mixed and prepared, and if the rebar is epoxy coated and protected from exposure to seawater, can be very resistant to wave impact and erosion.

***Figure 7. Cliff stabilization (soil nail wall) using concrete textured and colored to match existing cliff materials.***

Figure 8. Soil nail wall in the Pebble Beach area designed to look like the adjacent granite.

### *4.2 Impoundment or Placement Loss*

When any protection structure is built at the base of a bluff, cliff, or dune, or well out on the beach profile, a predictable amount of beach will be covered. The effect is immediate beach loss; the extent of the loss being a function of how far seaward and alongshore the structure extends. The type of structure is also important. Where a relatively thin vertical seawall or soil nail wall (gunnite) is built against the base of a cliff, bluff or dune, there is usually very little or no significant beach loss because such structures typically have very small cross-shore width, perhaps several feet. There are very large concrete seawalls, however, such as the O'Shaughnessy seawall along San Francisco's Ocean Beach (Figure 3), or the Galveston seawall, which do have a significant width and will cover over more beach area.

On the other hand, where riprap or a revetment is placed to protect a bluff, it may reach a height of 15 to 20 feet or more, and extend seaward at a 1.5:1 or 2:1 slope, covering 30 to 40 feet or more of beach (Figure 9). This placement loss can easily be determined for any proposed revetment knowing the cross-sectional

***Figure 9. Emplacement of riprap impounds or covers significant beach area.***

area and alongshore dimensions, and this impact analyzed in relation to how much adjacent or surrounding beach area is available.

### *4.3 Reduction of beach access-lateral or vertical*

Depending upon the type and configuration of the shoreline under consideration, and the nature of the protective structure, the potential exists with any armor to reduce or restrict access either to the beach (vertical access) or along the beach (horizontal access). In California, a major driving force for the passage of the original Coastal Act in 1976 was public access to the shoreline that was increasingly being threatened or restricted by oceanfront construction of all sorts.

Seawalls or other types of armor are usually built where and when construction on a seacliff, bluff, dune, or on the back beach is threatened by wave impact and/or erosion. If riprap or a revetment is constructed, a significant amount of beach will be lost with the placement of the structure on the beach (Figure 9). Depending upon the width of the beach and the tidal range, horizontal or lateral access may be lost for differing amounts of time throughout the year. Loss of lateral access will be greater in the winter months when the beach has been lowered and narrowed, than in the summer months when a wide berm usually forms. While seawalls normally extend less distance seaward than a revetment, both structures can restrict lateral access if the beach is narrow or only present seasonally.

Loss of vertical access is a somewhat different issue. Seawalls or bulkheads can restrict or eliminate access to the beach from the cliff or bluff top, but in most steep cliffed areas, vertical access is limited to begin with. Access stairs can be built into virtually any coastal armoring structure, however, so that this is an impact that could be mitigated, although these access stairs may also be damaged or destroyed by the wave action that led to the original need to armor.

### *4.4 Loss of sand supply from eroding bluffs/cliffs*

Armoring of cliffs, bluffs or dunes has also become an issue as it affects sand supplied to beaches on a regional basis. In California, the great majority (70 to over 95%) of the beach sand comes from rivers and streams, with most of the rest coming from eroding cliffs and bluffs. With a significant reduction in sand transport and delivery due to the construction of over 500 dams on coastal streams in California (Willis and Griggs, 2003), there is an increased awareness of the potential impacts of additional sand supply reduction. To the degree that a seawall or revetment armors an eroding bluff, the amount of beach-compatible material formerly provided by that bluff is removed from the littoral system.

Evaluating the impact of any proposed seawall or revetment involves determining how much littoral sand is supplied by the retreat of the particular bluff, cliff, or dune area being armored. One needs to know the alongshore length of bluff, the height of the bluff, the percentage of sand or littoral-size material in the bluff materials and also the average annual erosion rate. Measuring these components can be a challenging undertaking but knowing these values will allow you to calculate a volume of sand or beach-compatible material that would be eliminated through armoring.

With this number in hand ($yds^3$ or $m^3/yr$), one can now determine how important or significant this volume is relative to the littoral drift rate at that particular location, or what percent of the total amount of sand contributed to this cell is supplied by the area of bluff or cliff being considered. In the Santa Barbara and Oceanside littoral cells in California (Runyan and Griggs, 2003) it was determined that cliff erosion under natural conditions only supplied 0.4% of the total littoral material to the Santa Barbara cell, and ~10% of the sand to the Oceanside cell. There will be areas where armoring the cliffs, bluffs or dunes might have a significant effect on the littoral sand supply, and others where this will not be an issue, particularly relative to damming a river or stream.

### *4.5 Passive Erosion*

Whenever a hard structure is built along a coastline undergoing net long-term erosion or retreat as a result of sea level rise, the shoreline will eventually migrate landward behind the structure (Figure 10). The effect will be gradual loss of the beach in front of the seawall or revetment as the water deepens and the shoreface profile migrates landward. This process is designated as ***passive erosion*** and is the process that has been well documented along many of the armored barrier islands of the Atlantic coast, as well as on Oahu (Fletcher, et. al., 1997), and along the coast of California and Washington. This process takes place regardless of the type of protective structure emplaced. While there are widespread observations and perceptions that beaches along many coastlines are narrowing or eroding, hardening the coastline with seawalls or revetments and the passive erosion that follows (Figure 11) may be as important a factor as an actual decline in the availability of beach sand. The process of passive erosion is perhaps the most significant long-term effect of shoreline armoring.

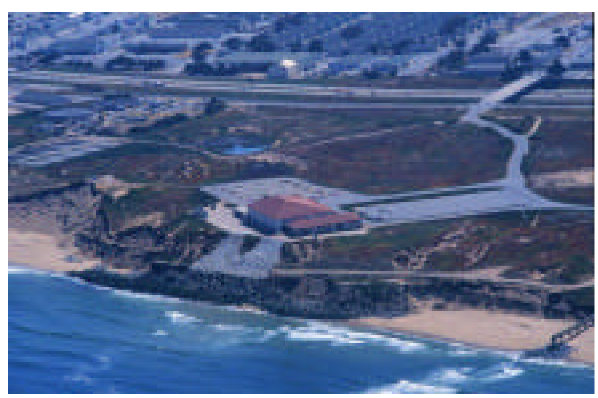

***Figure10. Passive erosion or loss of beach in front of riprap in central Monterey Bay, with a beach to either side where bluffs have not been armored.***

### *4.6 Active Erosion*

The ability or potential for a seawall or revetment to induce or accelerate erosion, has been the source of considerable controversy over the past two decades. One of the most commonly repeated assertions is simply that seawalls cause beach erosion or accelerate the erosion of adjacent unprotected cliffs

***Figure 11. The placement of riprap to protect this low bluff south of San Francisco has led to the loss of beach due to a combination of placement loss and passive erosion.***

or bluffs. Although differing opinions have been put forward regarding the impacts of protective structures on adjacent beaches, until fairly recently there had been a noticeable lack of sustained or repeated field observations and measurements with which to resolve the conflicting claims. Two major compilations of existing studies and references related to the issue of seawalls and their effects on beaches have now been completed (Kraus, 1988; Kraus and McDougal, 1996).

The potential for a seawall or revetment to induce or accelerate beach erosion has also been the source of controversy over the past decade. We recently completed an 8-year study monitoring the impacts of several different types of seawalls and revetments on fronting and flanking beaches in northern Monterey Bay, California. While there are local small scale seasonal impacts which we have documented (Griggs, et. al. 1997), there are no permanent effects on the beaches studied, which are along a shoreline which has a high littoral drift rate and is not undergoing any net long-term erosion, but does undergo regular seasonal changes. While riprap revetments have often been perceived and judged by permitting agencies to be more permeable and therefore expected to have less impact on beaches than "impermeable" seawalls, this was not supported by field observations and surveying (Griggs, Tait and Corona, 1994).

**5. DISCUSSION AND CONCLUSIONS**

While several states have banned all new hard protective structures, proposals for new seawalls in California are still frequent but face increasing public and increased Coastal Commission scrutiny. Simultaneously, local governments have organized to lobby for beach replenishment and nourishment. Their objectives are to widen or rebuild beaches that could provide increased recreation area for both tourists and residents, and also help buffer the coastline from wave attack. Arguments have been made that the beaches of California are eroding due to sand supply reduction. While significant impoundment of upstream sand supplies from the streams draining into the littoral cells of southern California has been well documented, it is not clear that this reduction has been directly reflected in sand supply at the coastline. To date, there have been no long-term assessments of systematic regional change in beach width or volume. The artificial widening of many beaches between the 1940's and the 1960's due to sand nourishment from the many large coastal construction projects, however, complicates any evaluation of long-term beach change in southern California. The beaches of the Santa Monica cell, for example, have been gradually returning to their natural widths at a time when sand reduction from dams and other diversions, and a return to more frequent and severe ENSO events, have significantly impacted the beaches of portions of southern California.

Over the past 50 years, the typical response to coastal hazards in California has been the construction of seawalls or revetment intended to protect eroding or wave-impacted coastlines. An astonishing 10 percent of the entire coastline of California is now armored. Protective structures have usually been constructed only after existing shoreline development has been threatened.

Significant changes are needed in how we approach and deal with coastal retreat and the continuing pressure to develop and armor oceanfront properties. The marked inconsistencies among local governments and those state agencies, which have responsibilities to regulate development indicate the lack of a guiding direction and the heavy influence of local economics and politics. Through a process of hazard recognition and evaluation, and then a standardized set of avoidance, mitigation, or hazard reduction policies, the private and public losses from future coastline erosion, storm impact, and sea level rise can be significantly reduced. The objective is to reduce the number of people, as well as dwellings, structures, and utilities, both public and private, directly exposed to the hazards of shoreline erosion.

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