STATE OF CALIFORNIA—NATURAL RESOURCES AGENCY EDMUND G. BROWN, JR., *GOVERNOR*

CALIFORNIA COASTAL COMMISSION

45 FREMONT, SUITE 2000
SAN FRANCISCO, CA 94105- 2219
VOICE (415) 904- 5200
FAX (415) 904- 5400
TDD (415) 597-5885

W6e

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TO: Commissioners and Interested Parties

FROM: John Ainsworth, Executive Director
Susan Hansch, Chief Deputy Director
Lesley Ewing, Ph.D. PE, Sr. Coastal Engineer
Joseph Street, Ph.D., Staff Geologist

SUBJECT: Briefing on shoreline protective devices and their effects on beaches and coastal processes. **Informational item only – no Commission action**.

I. BACKGROUND

The modification of coastlines through the construction of shoreline protection structures has been increasing worldwide, driven by expanding coastal populations and development (Coyle and Dethier 2010). The 1,270-mile mainland California coast faces similar pressures. Many Californians live, work or vacation in coastal counties and contribute to a $40 billion dollar coastal economy based in large part on the state's beaches, coastal recreation areas and unsurpassed natural beauty. However, California's coastal communities are faced with a historical legacy of existing development built in close proximity to the shoreline, in areas at risk of flooding and coastal erosion, and a continued high demand for new development along the coast. Past erosion and flooding events have caused significant damage to public infrastructure, private property, beaches and recreational opportunities and other coastal resources; accelerating sea level rise will amplify the risks and potential damages to development and coastal resources in many of California's shoreline areas.

Governments and private property owners have typically responded to threats of coastal erosion with various strategies of shoreline protection: the construction of seawalls, revetments, breakwaters, and other "hard" armoring; or beach replenishment efforts using sand dredged from harbors or other sources. In aggregate, shoreline protection efforts have achieved a degree of success in protecting coastal development, but in doing so have substantially modified large portions of the coast, with significant and often underappreciated impacts on coastal resources. As discussed in more detail below, shoreline protective devices (SPDs) can adversely affect public access, recreation, and shoreline ecology by taking up usable space on beaches, reducing sand supply, and limiting the natural adaptive capacity of beaches to adjust to sea level rise, storms events, and other perturbations.

This report will provide a brief introduction to the natural processes that cause coastal erosion and shoreline retreat, and a discussion of current methods of shoreline protection and their consequences, both intended and unintended, for California's beaches and other coastal assets.

II. COASTAL ACT FRAMEWORK

Shoreline protection devices have significant impacts on many important coastal resources; including public access, recreation, marine and land resources, environmentally sensitive habitats, scenic resources and community character. While most of Chapter 3 of the Coastal Act addresses resources that can be affected by shoreline protective structures, there are two key sections that most often are assessed when shoreline protection is a concern. Those are Section 30253 of the Act, which covers new development and steps to avoid the need for future protection measures; and Section 30235, which provides for the specific, limited situations in which shoreline protection must be permitted.

III. MECHANISMS OF SHORELINE RETREAT

Coastlines evolve in response to oceanographic and geologic processes occurring on a variety of timescales. Over geologic time, tectonic processes causing uplift or subsidence determine the large-scale character of the California coast. At much shorter time scales, locally-significant changes to the coast, such as bluff collapse or beach sand loss, can occur rapidly during a single winter storm event. On timescales in between, ranging from days to thousands of years, the coast is shaped by tides and currents, wave magnitude, frequency, and direction, changes in the littoral cell sand supply from rivers and other sources, climatic cycles (e.g., El Niño), and changes in sea level.

Bluffs and cliffs

Coastal cliff or bluff retreat occurs as a result of several different processes, including wave attack, landslides and other mass movements, subaerial erosion and seismic shaking. Wave attack drives bluff retreat by eroding material at the bluff toe, leading to the undercutting, oversteepening of the bluff slope, and the eventual failure of upper bluff materials until a more stable bluff profile is reestablished. The degree to which a bluff erodes in response to wave attack and subaerial processes is related to the physical properties of the rock or sediment that comprise the bluff, and also the level of exposure to wave attack, runoff, and other drivers of erosion. The resistance of a cliff material to erosion is directly affected by its hardness and cohesion ("lithology"), as well as the presence of internal weaknesses, such as joints, fractures or faults. Bluffs composed of unconsolidated sediments are particularly vulnerable to wave attack and erosion due to the lower strength and cohesion of these materials, and may be at much greater risk of a landslide or other failure when saturated with surface water or groundwater.

Beaches

A beach is a mobile, temporally-variable expanse of sand, cobble, silts, gravel or other loose material (collectively called beach sediment) that forms at the edge of the shoreline, between the ocean and less-mobile inland features, such as a backshore bluff, line of permanent vegetation, or a fixed structure. Beach sediments derive primarily from inland areas, via the transport of sediment by rivers and streams of from the erosion of coastal bluffs; and from the onshore transport of offshore deposits by waves and currents. Humans can alter beach sediment supplies by either adding additional sediment to a location (beach nourishment), removing sediment (beach mining), or modifying the flow of sand into or out of an area (e.g. damming of streams, installation of groins). Beach sediment is mobile, subject to forces by waves, currents and wind and it is regularly being moved into and away from various beach areas. Beach accretion (growth) occurs when more sediment moves into an area than leaves. Beach erosion occurs when more sediment leaves an area than is moved into it.

A beach shoreline is a three-dimensional system, and the dry sand areas typically used for recreational activities are only a small part of the overall sand system. Sandy beach sediments occur within a relatively shallow nearshore zone, where ocean waves have enough energy to pick up the sand and transport it across and along the shoreline. In California, this zone of active beach sediment movement typically extends to a water depth of 30 to 40 feet below Mean Sea Level (MSL). In addition to the horizontal distribution of beach sediments along the shore and into the offshore, beaches have a vertical dimension of depth or thickness of the sediment layer.

In a dynamic coastal setting, all three of these beach dimensions change in response to changes in the sediment supply, wave energy or other shoreline conditions. During calmer periods, waves carry sediment from the offshore to the beach and cause the beach area to grow. This typically occurs during spring and summer and is the source of the wider summer beaches that are often observed along the California coast.

During storm periods with large, high-energy waves, sand is often carried away from the dry beach and deposited in offshore bars or submerged berms. The submerged bars and berms store sand and help protect the backshore (and by extension, everything behind it) by causing large waves to break on the bar, releasing some of their energy offshore rather than directly against the backshore. Despite the submerged sand, the wave energy in large storms is often sufficient to pound against a back beach zone, causing erosion of the back dune or coastal bluff. While bluff sediments can be supplied to the coast throughout the year, it is often during these large storm events that bluff erosion is greatest. For a dune-backed beach, the loss of sediment from the dune during times of large storms can be reversed as waves bring sediment back up onto the beach, where it can be either deposited directly onto the dunes, or carried by wind onto the dunes. For bluff-backed beaches, the eroded bluff sand will help supply sediment to the beach, but this beach sediment will not be returned the bluff, except as a result of very long-term geologic processes (i.e., formation of new marine terrace/bluffs through tectonic uplift and/or large changes in sea level).

Effects of Sea Level Rise
Sea level rise is expected to exacerbate existing coastal hazards by raising mean water levels, extending flood zones inland, and increasing the frequency and magnitude of beach and bluff erosion events. As noted in the Commission's 2015 Sea Level Rise Guidance and other studies, increased sea level is expected to cause increased inundation of beaches, reduced accretion or increased erosion of beaches, and more rapid retreat of bluffs.

IV. SHORELINE PROTECTIVE DEVICES & EFFECTS ON BEACHES AND COASTAL PROCESSES

From a geologic standpoint, beaches and seacliffs are ephemeral features that continually adjust in response to sea level, waves, subaerial erosion, gravity and tectonic processes. At times, historical patterns of coastal development have overlooked or underestimated the dynamic nature of coastal landforms, and the degree of hazard posed by on-going shoreline retreat. As a result, many permanent structures – buildings, roads, railroads, utility lines, power-plants and wastewater treatment plants, to name a few – have been constructed in areas exposed to shoreline erosion or wave attack. In California, much of the existing coastal development and infrastructure either was located in areas that were known to pose coastal hazards, such that shoreline protection was installed at the time of initial construction, or was located in areas where coastal hazards have necessitated shoreline protection over time. Human activities, in particular the damming and withdrawal of water from coastal rivers and streams, and the widespread emplacement of shoreline armoring, have significantly reduced the natural supply of sand to the shoreline (e.g., Willis and Griggs 2003), contributing to the narrowing of many beaches and a reduction in their capacity to serve as buffers against the erosive effects of storm waves. A previous study has estimated that, as a result of these pressures, approximately 10% of the mainland California open ocean coast has been armored (Griggs, 2005). A new inventory of shoreline armoring (2018 Coastal Armoring Database) being developed by Commission Mapping Unit staff indicates that this percentage is much higher in the heavily-developed counties of southern California. For example, preliminary results from the Commission's Armoring Database show that approximately 30% (about 23 miles) of San Diego's outer coast is armored by some type of shoreline protective device. This is based on the Commission's 2010 mileage estimate of 76.5 miles of outer coastline for San Diego County.

Historically, the most common societal response to coastal hazards has been to construct *shoreline protective devices* (SPDs) in order to slow the erosion of beaches and bluffs, retain unstable slopes, and prevent flooding. In many places, protective structures such as jetties and breakwaters have been extended offshore to protect against waves and modify patterns of sand movement and deposition. Though varying considerably in terms of their design, size, cost, lifespan and effectiveness, the common purpose of all SPDs is to halt or show the natural, dynamic processes that shape the coast – essentially, to "fix" a portion of the shoreline in a particular configuration. These human interventions in natural shoreline processes have resulted in a variety of intended and unintended consequences.

Shoreline Protective Devices: Vertical Seawalls, Revetments & Upper Bluff Protection

Seawalls, revetments and upper bluff protection structures are by far the most frequently used forms of SPDs along the California coast. SPDs constructed near sea level or at the toe of a bluff are primarily intended to deflect or dissipate wave energy, protecting against marine erosion; upper bluff devices typically retain weak natural materials and/or protect against subaerial erosion processes. Often, specific sites may combine one or more efforts – seawalls with upper bluff protection, seawalls fronted by revetments for toe protection, or the use of hybrid structures.

Vertical seawalls are upright structures, constructed of steel, concrete, or wood and oriented parallel to the shoreline, which are intended to provide barriers to wave attack and marine erosion, and/or retain and prevent the failure of weaker materials. Most existing seawalls have been built along straight sand beaches or coastal bluffs. Some older seawalls were placed seaward of the natural shoreline as a means of extending the buildable land area; typically, fill was placed landward of the seawall so that buildings, roads or other development could be constructed on the fill (the O'Shaughnessy Seawall in San Francisco is an example of this type of wall). More recently, seawalls along steep coastal bluffs have included a facing of colored and textured shotcrete to help them mimic the visual appearance of the native bluffs. These walls are often combined with upper bluff retention devices in order to stabilize both the bluff toe and the full bluff face.

Revetments are facings of stone, rock or concrete supported on and built to protect a scarp, embankment, bluff toe, or shore structure from erosion by wave action or currents. Revetments are commonly used at the toe of bluffs for scour protection and to slow bluff retreat, but are also built along open beaches, lagoons, and river banks to protect landward development.

Upper bluff protection includes any type of stabilization or retention device used on an upper bluff area to prevent erosion, slumps, slides or other types of bluff loss. Typical upper bluff protection devices include retaining walls, ground anchors, rock anchors, soil nails, piles, reinforced earth, grouting, chemical stabilization, and shotcrete and gunnite facings. In some situations, foundation structures, such as deep-seated piles, caissons or tie-backs, function as de facto upper bluff protection where they stabilize the bluff and impede natural erosion processes.

Effects of Seawalls, Revetments and Upper Bluff Protection on Coastal Processes

To varying degrees, SPDs of all types have similar physical effects on beaches and coastal processes. All SPDs are physical structures that take up space and displace or modify prior uses of coastal land (e.g., beach recreation, habitat, etc.); this effect is often referred to as **encroachment**. Seawalls and, in particular, revetments, may have large horizontal footprints, displacing what would otherwise be sandy beach, and resulting in a long-term loss of beach area for public access, recreation and other uses.

In addition to encroaching onto the beach, SPDs, by slowing or stopping natural processes of shoreline retreat, also prevent the future creation of new beach and eliminate a supply of new sand that would otherwise have resulted from bluff and shoreline erosion. By design, SPDs establish a fixed landward boundary of the back beach ("fixing the back beach"), and prevent the natural, on-going inland adjustment of the beach that occurs on an eroding coast; over time, this restriction of a beach's adaptive capacity can result in the narrowing or loss of the beach ("**passive erosion**"). Future sea level rise is expected to result in the drowning or "pinching out" of many California beaches (Vitousek et al. 2017), an effect that will only be exacerbated in locations with extensive shoreline protection. Along coastlines dominated by cliffs and bluffs, SPDs also reduce or eliminate the additional supply of sand provided to local beaches by natural bluff erosion. This "**retention of beach material"** or "sand supply impact" associated with SPDs contributes to local and regional (i.e., littoral cell) sand supply deficits, and hastens the effects of passive erosion.

By substituting hard materials (e.g., rock, concrete) in place of more erodible natural substrates (e.g., sand, soils, terrace deposits, sedimentary rocks), SPDs can also change wave reflection patterns, cause scour or winnowing of beach sediments along the shoreline, and increase erosion rates at unarmored locations up- and down-coast of the structure ("end effects"). In certain locations, SPDs may also interrupt or interfere with longshore and cross-shore sediment transport, resulting in deposition of sand in one location at the expense of other locations further "down drift" along the coast. Broader effects of SPDs include changes to the recreational and beach use experience, impacts to beach and other coastal ecosystems, and impairment of the aesthetic and visual character of the coast.

The three primary physical impacts of SPDs (encroachment, fixing the back beach/passive erosion and sand retention) are illustrated in **Figures 1 – 5** (Exhibits), and will be discussed in greater detail in the briefing in front of the Commission. We emphasize these primary effects of SPDs because (along with beach scour) they each result in the loss of beach area, either immediately (i.e., encroachment) or over time (passive erosion, loss of sand supply), and of the public access, recreational, ecological and aesthetic benefits that beaches provide. All of the identified adverse effects of shoreline protective devices are of concern, and should be fully evaluated, and where necessary, mitigated, in order to maintain and preserve the coastal resources and uses protected under the Coastal Act.

V. REFERENCES, RESOURCES & FURTHER READING

Coyle, J.M., and Dethier, M.N. (2010). Appendix C: Review of shoreline armoring literature. In: Shipman, H., Dethier, M.N., Gelfenbaum, G., Fresh, K.L., and Dinicola, R.S. (eds.), *Puget Sound Shorelines and the Impacts of Armoring—Proceedings of a State of the Science Workshop, May 2009*, U.S. Geological Survey Scientific Investigations Report 2010–5254, p. 245-265.

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Vitousek, S., Barnard, P.L., Limber, P. (2017). Can beaches survive climate change? *Journal of Geophysical Research – Earth Surface* 122: 1060-1067, doi:10.1002/2017JF004308.

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VI. EXHIBITS – SHORE PROTECTION IMPACTS

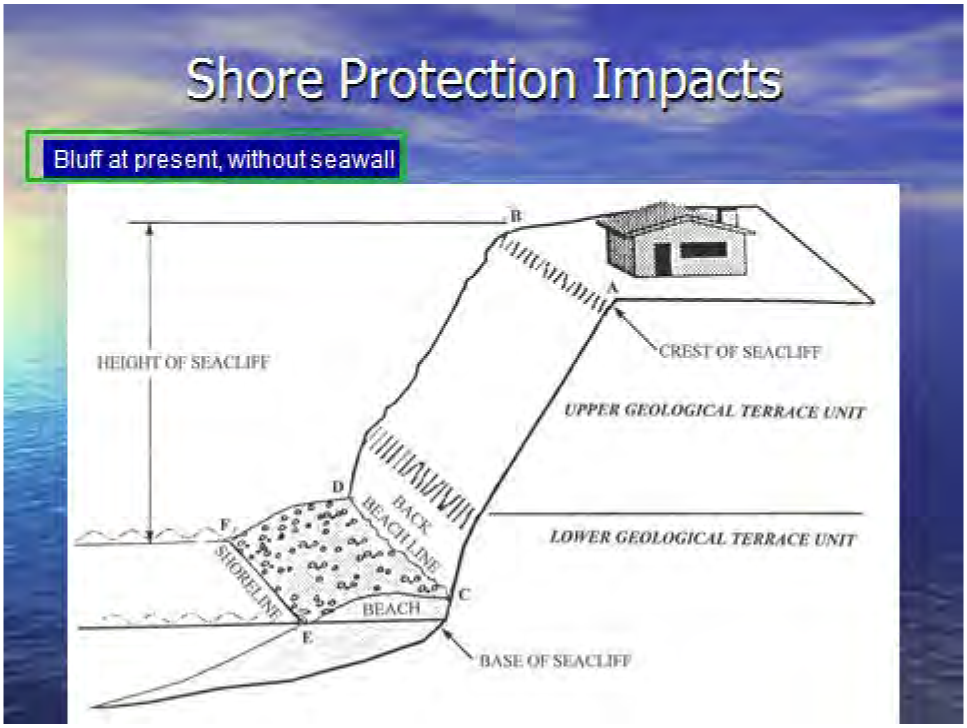

Figure 1: Bluff at present, without seawall. (Source: L. Ewing, CCC)

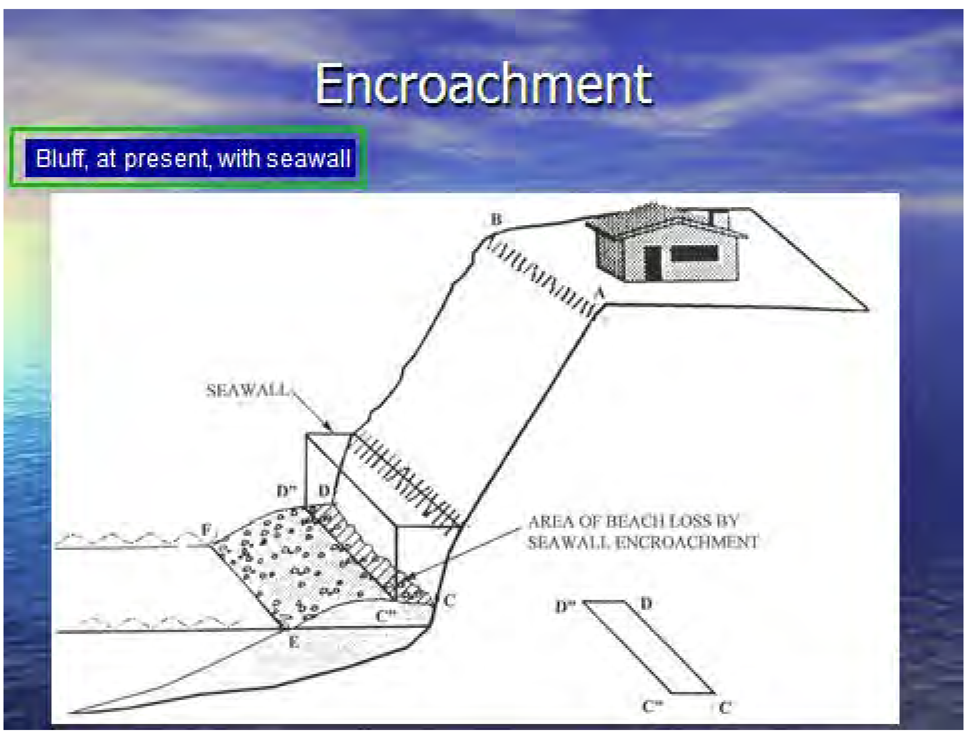

Figure 2: Encroachment, bluff at present, with seawall. (Source: L. Ewing, CCC)

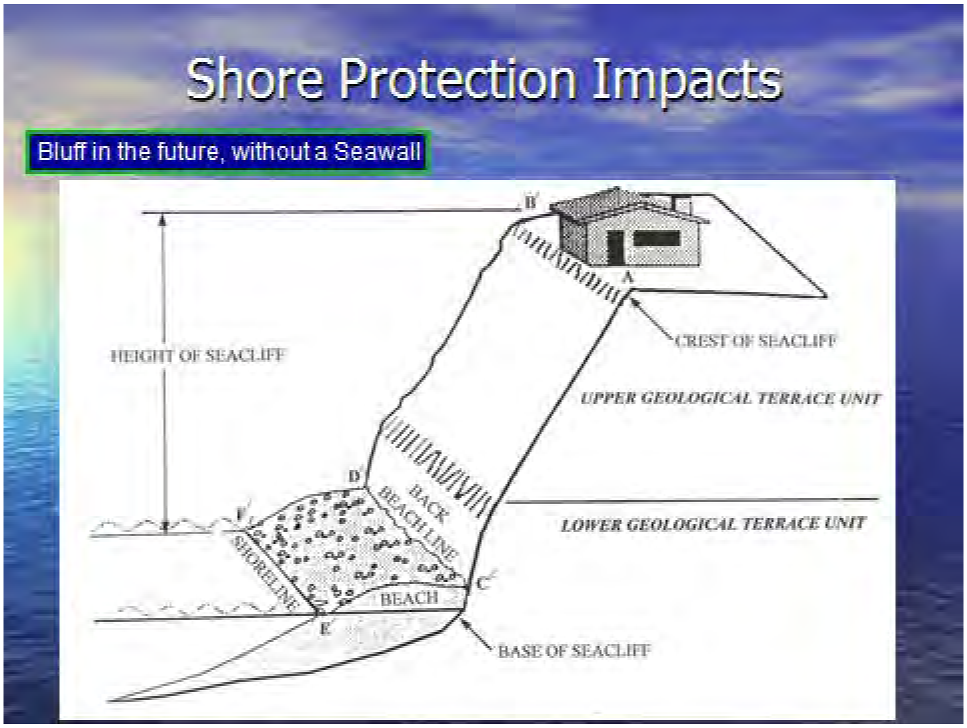

Figure 3: Bluff changes in the future, without a seawall. (Source: L. Ewing, CCC)

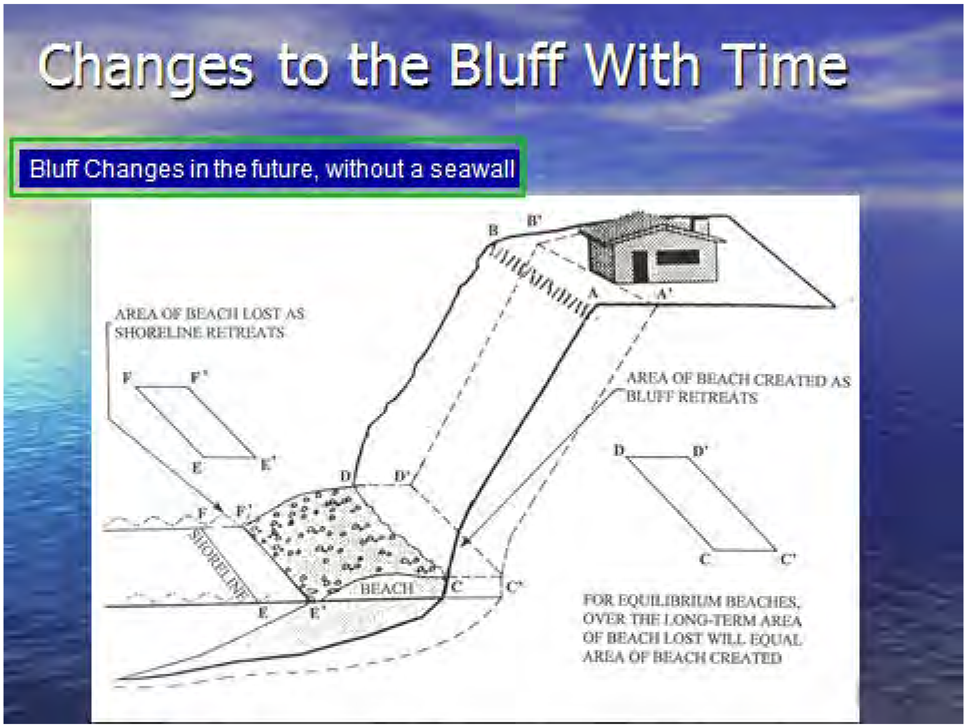

Figure 4: Bluff changes with time, without a seawall. (Source: L. Ewing, CCC)

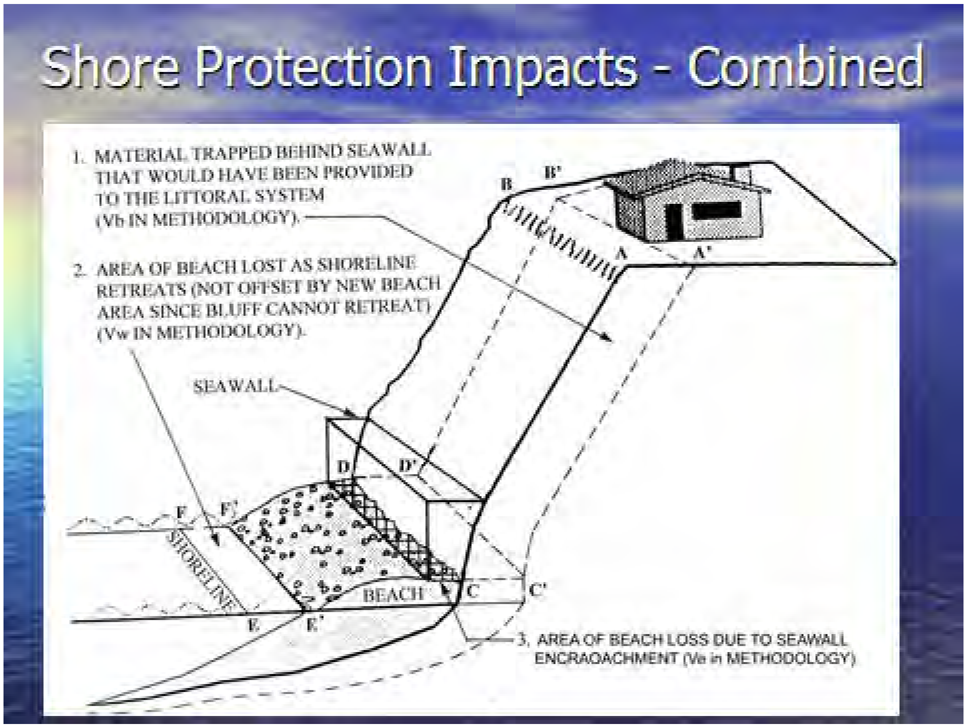

Figure 5: Bluff changes, in the future, with a seawall. (Source: L. Ewing, CCC)