Staff Report

PROTECTING SHORELINE PROPERTY FROM TIDAL EROSION:

AN ANALYSIS OF THE EFFECTIVENESS AND ENVIRONMENTAL IMPACTS OF ADMINISTRATIVELY AUTHORIZED PROTECTIVE STRUCTURES

November 1988

San Francisco Bay Conservation and Development Commission

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INTRODUCTION

During the public reviev/ of the staff report on Commission Mitigation Practices (March 1987),. some testimony was received alleging that the individual and cumulative impacts of administratively authorized projects classified as "minor repairs and improvements" might be significantly affecting Bay resources. In an effort to understand how these minor.fills are impacting the Bay, the Commission initiated a study of the most common category of minor fill projects administratively authorized--the installation of structures to protect shoreline property from tidal erosion. In particular, the Commission asked the staff to determine; (1) the number of projects and the amount of fill administratively authorized for shoreline erosion control; (2) how such fills may be impacting Bay resources; (3) whether approved projects adequately protect shoreline property from erosion; (4) whether alternative erosion control measures exist that v/ould better protect shoreline property and minimize the amount of Bay fill and adverse impacts on Bay resources; (5) whether mitigation for proposed erosion control fill projects should be required; and (6) whether the Commission should change its procedures and practices concerning mitigation for administratively authorized fill for minor repairs and improvements.

This report addresses the concerns the Commission instructed the staff to analyze. The first chapter reviews the Commission's authority to authorize fill for shoreline erosion control, describes the environmental analysis typically given to such projects, and discusses local, state, and federal government practices in reviewing and authorizing erosion control structures.

Chapter II describes the forces which act to erode shorelines and discusses natural defenses to these erosive forces.

Chapter III reviews erosion control structures and measures that are commonly employed to halt or slow shoreline erosion, their relative costs and effectiveness, their environmental impact, and the factors that typically lead to failure of protective structures. This chapter focuses on those structures and measures that have been used, or have the potential for use, in San Francisco Bay.

Chapter IV discusses the methods used to evaluate the individual and cumulative impacts of administratively authorized projects for protecting shoreline property from tidal erosion in San Francisco Bay. This chapter also calculates the approximate amount of Bay shoreline, surface area, and volume that have been affected by administratively authorized shoreline erosion control projects during the ten year study period.

In Chapter V, shoreline uses protected by erosion control efforts are described, including the public benefits derived from their protection.

Chapter VI evaluates the Bay resource impacts of administratively authorized shoreline erosion control projects over the past ten years. This chapter summarizes field observations of the environmental impact and effectiveness of these projects, describes alternative protective strategies that hold promise for use in San Francisco Bay, and discusses some of the practical considerations of requiring more extensive Commission and staff review of such projects. This chapter specifically addresses whether mitigation should be.required to offset the impacts of such fills.

Chapter VII presents the staff's conclusions based on it's review of the literature, permit files, and field investigations.

The report concludes with recommendations for improving the Commission's knowledge of how such projects will impact Bay resources, assure that protective structures are properly designed to increase their effectiveness and reduce, their impacts, and the circumstances for which mitigation may be appropriate.

CHAPTER I.
AUTHORITY TO AUTHORIZE EROSION CONTROL STRUCTURES

This chapter summrizes the Commission's authority to permit fill to protect shoreline property from tidal erosion, the policies and procedures currently used to authorize most such filling administratively, and the environmental analysis typically given to such projects. A second section briefly explains the authority, policies and procedures of other governmental agencies which regulate shoreline protection projects.

Commission Authority

Section 66632 of the California Government Code requires "...any person or governmental agency wishing to place, fill, to extract materials, or to make any substantial change in use of any water, land or structure, within the area of the commission's jurisdiction..." to first obtain a permit. The section goes on to define fill broadly to include" ... earth or any other substance or material..." Section 56510 of the California Government Code defines the area of the Commission's jurisdiction to include all areas subject to tidal action within the Bay, and a shoreline band consisting of the first 100-feet inland from the line of highest tidal action.

Typically, work to protect shoreline property from erosion is placed in the Bay in the form of levees, breakwaters, groins or other structures in the water. Additionally, protective work also often involves fill or structures in the shoreline band. Consequently, almost all work to protect land or structures from the erosive effects of bay tidal forces occurs within the commission's jurisdiction and requires a permit.

Most shoreline protective projects are reviewed administratively by the executive director. Section 66532(f) of the California Government Code, in part, states:

> ...the Commission may provide by regulation, adopted after public hearing, for the issuance of permits by the executive director... in cases of emergency, or for minor repairs to existing installations or minor improvements made anywhere within the area of jurisdiction of the Commission including, without limitation, the installation of piers and pilings and maintenance dredging of navigation channels.

Pursuant to this authority the Commission adopted section 10601(a)(5) of the California Administrative Code, Title 14, which allows the executive director to grant administrative permits for:

> the installation of new protective works and repairs to existing protective works, such as bulkheads and riprap, in the minimum amount necessary to stabilize existing dikes and banks and to provide improved fish and wildlife habitat.

Most of the projects analyzed in this report were approved pursuant to this above section. Another and more general section allows administrative action on projects involving minor fill for improving shoreline appearance or public access that does not exceed 1,000 square feet in area. Shoreline protection may be an element of such projects.

The executive director grants or denies an administrative application based upon the same analysis and findings that the Commission relies upon when it acts on applications requiring a public hearing. To grant an administrative permit, the executive director must be able to find that the project is either: (1) necessary to the health, safety, or welfare of the public in the entire Bay Area; or (2) is consistent with the provisions of the

McAteer-Petris Act and the policies of the San Francisco Bay Plan (California Government Code Section 66632(f)).

Generally, the McAteer-Petris Act limits fill projects that may be authorized to those where the public benefits from the fill clearly exceed the public detriment from the loss of water area displaced by the fill, and to fills for water-oriented uses such as ports, water-related industxies, airports, bridges, wildlife refuges, water-oriented recreation and public assembly, water intake and discharge lines- for desalinization plants and power plants or for minor fills for improving shoreline appearance or public access to the Bay. However, the water-oriented uses listed in the law are exemplary, not all-inclusive; the Commission may treat other uses as water-oriented, if factually the use is related to and depends on the Bay to function. Through the adoption of Section 10601(a)(5) of the regulations, the Commission has determined that shoreline protection is a water-oriented use.

Administrative applications must be listed with the Commission at least five days prior to a regularly scheduled Commission meeting (Section 10620 of the California Administrative Code, Title 14). Prior to acting on listed application, the executive director must wait fourteen days following the mailing of a listing to the Commission, or after the first scheduled Commission meeting, whichever comes first. This gives an opportunity to a Commissioner to communicate with the executive director either prior to or at a scheduled meeting that a project should be reviewed by the Commission. If such action is taken by a majority vote of the Commission, the executive director may not issue or deny the administrative application. Instead it is treated as though it were an application requiring a public hearing before the Commission (Section 10621 of the California Administrative Code, Title 14).

The Bay Plan does not specifically discuss shoreline protection or establish policies for determining which types of protection projects are appropriate and which are not. If the Commission determines that greater scrutiny over shoreline protection projects is necessary, policies should be developed and included in the Bay Plan.

Environmental Review

Both the Comission and, for delegated administrative actions, the executive director, must comply with the California Environmental Quality Act (CEQA). While local government will often be the "lead agency" for CEQA purposes, many shoreline protection projects do not require a discretionary local permit. In such cases the Commission will be the lead agency. Generally, CEQA requires the preparation of an environmental document (an environmental impact report or a negative declaration) when a project is likely to have a significant adverse impact on the environment. Prior to undertaking an analysis of the existence and extent of any adverse impact, however, it must first be determined whether the project is exempted from the need to prepare a document pursuant to a statutory or regulatory provision. In this regard Section 11501 of the California Administrative Code, Title 14 states that shoreline protection projects are:

> ...usually categorically exempt...provided that such projects will not be considered categoricaly exempt when they either: (1) may have an adverse impact on an environmental resource or involve a hazard of critical concern; or (2) may have a cumulative adverse impact when considered with successfully similar projects.

Nearly all of the projects reviewed in the report were determined to be categorically exempt from the need to prepare an environmental document.

The fact that a project may be categorically exempt from the need to prepare an environmental document does not necessarily mean that the project will have no adverse impacts. If a project has adverse impacts, regardless of whether an environmental document is prepared, the Commission as lead agency may impose conditions to require that the adverse impacts be mitigated. The authority to impose mitigation conditions arises from the McAteer-Petris Act. Mitigation conditions were not imposed for any of the projects reviewed in this report.

In the past, when the Commission has been the lead agency, very fev/ environmental documents have been prepared. This is permissible because the information and analysis required to analyze a project under the Commission's laws and plans is similar to the information that would be presented in an environmental document. Thus, the Commission's regulatory policies and procedures assure that the environmental impacts of a project will be presented and analyzed. Moreover, if necessary, conditions to alleviate or offset the negative and avoidable impacts of projects will be imposed. Regulatory programs which assure that such information will be available and acted upon can be determined by the Secretary for Resources to be the "functional equivalent" of the Environmental Impact Report (SIR) process pursuant to Resources Code Section 21080.5. The Secretary for Resources has so certified the Commission's regulatory and planning programs.

Typical findings in administrative permits for erosion control projects state that: (1) the public benefits of the small amount of fill necessary to protect shoreline uses and improvements from the hazard of tidal erosion clearly exceed any public detriment from the small amount of water area lost; and (2) the project is categorically exempt from the requirement to prepare an environmental document.

Local Government Actions

The Commission shares regulatory and environmental authority over construction of shoreline protection measures in the Bay with local government and the U. S. Army Corps of Engineers.

A sampling of several Bay Area local governments indicates that, typically, discretionary approval is not required for projects consisting only of shoreline protection. Only when the shoreline protection is part of a larger project local discretionary approval is required. Some local governments require a grading permit for shoreline protection projects; others ministerially approve such projects and issue over-the-counter permits upon the completion of a short application and the payment of a fee. Ministerial actions are usually exempt from the requirements of CEQA so local governments do not often gather environmental data about the site or analyze the likely impacts of the shoreline protection work.

The 40 Commission permits involving the greatest amounts of fill for protective structures (that is 10,000 square feet or more) were reviewed co determine what action local government and U. s. Army Corps of Engineers took regarding these projects. Twenty-five of the 40 projects (52 percent) required no local government approval, five (12 percent) required grading permits, five (12 percent) were approved as part of a discretionary approval for a larger project, and the remaining five projects (12 percent) required other kinds of local approval such as a master development agreement. Of these 40 projects, 13 were found to be categorically exempt by the local government. Mo environmental document was prepared on 14 others but no reasons were given; presumably it was determined that the projects were categorically exempt. Negative declarations of environmental impact were certified for seven of the projects. Five projects relied on EIRs or-EISs but the protective structures v-zere relatively minor parts of much larger projects did not analyze possible impacts of protecting shoreline property. One project relied on an initial study which indicated that the protective structure would have no adverse impact on the environment. In no case did a local agency require mitigation for the shoreline protection project.

United States Army Corps of Engineers

Shoreline protection projects usually require approval by the Corps of Engineers because they involve fill in a navigable water over which the Corps exercises Section 10 permit authority (33 U.S.C. Section 403) or because they involve fill in waters of the United States over which the Corps exercises Clean Water Act authority (33 U.S.C. Section 1344). Usually the Corps does not analyze individual shoreline protection projects because they are covered by bank statalization nationwide permit (33 CFR Section 330.5(a) (13) which authorizes the placement of fill or structures to stabilize a shoreline if less than 500 feet of shoreline is involved or if there will be less than 1 cubic yard of material place per linear foot of shoreline. Only clean fill of the minimum amount necessary may be used. The nationv/ide permit does not, however, apply to work in marshy areas (technically "wetlands" as defined oy the federal government).

Concerning the U. S. Army Corps of Engineers' action on the 40 projects analyzed in this report, three of the projects met the criteria for a regionv/ide permit used by the San Francisco District before the nationv/ide permit became effective, five met the criteria of a nationwide permit, and 13 were issued a Corps permit with no special conditions attached. There was no project information in the Commission's permit files on what Corps action was taken in regard to 19 of the 40 erosion control projects. None of the Corps-issued permits required mitigation as a condition of project approval.

3ased on a review of the administratively authorized shoreline protection permits involving Bay fill over the past ten years, it is clear that the Commission, local government, and the Corps of Engineers treat small amounts of fill for controlling shoreline erosion similarly: the projects are, if and when permits are required, generally handled administratively. The projects are usually determined to be categorically exempt from the requirement of preparation of an environmental document. Further, mitigation has not been required as a condition of approval of these kinds of projects by local government, the Commission, or the Corps of Engineers.

CHAPTER II.
COASTAL PROCESSES

Storms, wind, waves, rain, water runoff, vertical and hortizontal land movement, and changes in water level continually reshape shorelines. For 86 percent of the California coastline, and for most of San Francisco Bay, this dynamic interplay of land and water has resulted in the shoreline retreating inland. In urbanized San Francisco Bay,' such retreat has, and v/ill continue to threaten buildings, roads, recreation facilities, and farmlands. As a result, ov/ners of bayfront property subjected to these physical forces must decide whether to: (1) let erosion proceed unchecked, and lose property and buildings; (2) move structures away from eroding shoreline areas; (3) construct buildings inland further from the shoreline; or (4) protect and stabilize the shoreline.

Natural Processes of Shoreline Erosion

Rates of shoreline erosion vary widely, depending on shoreline form, cock or soil type, prevailing winds, storm severity, fetch (the unobstructed distance over water in which waves are generated by wind of relatively constant direction and speed), and wave energy (force and power of a v;ave). There are three basic natural kinds of shorelines found in San Francisco Bay; cliffs or bluffs, marshes, and beaches. Cliffs or bluffs are steep rock formations where the erosion rate is determined largely by the rock type, wave action at their base, and groundwater seepage that weakens the cock formation. In San Francisco Bay, cliffs or bluffs are found around San

Rafael, Tiburon, north Richmond, the Carquinez Straits, the headlands of the Golden Gate, and Coyote Point in San Mateo. Marshes are vegetated, low erodible plains frequently inundated by tidal action. Marshes provide some measure of shore protection in low wave energy areas because the roots of marsh plants anchor Bay sediment while the aerial portion of marsh plants both dampen waves and trap water-borne sediment. As sediment is deposited, the resulting shallow foreshore (the shoreline area between the upper limit of the wave wash and low water; see Figure 1) causes waves to break farther offshore. Prior to 1850, marshes were the most prevalent kind of shoreline in San Francisco Bay. However, with diking and filling of the Bay prior to the creation of the Commission, only ten to 15 percent of Bay tidal marsh remains. Beaches are gentle slopes covered with loose material ranging in size from fine silts to cobbles. In San Francisco Bay, natural beaches are often found at the base of bluffs or cliffs and in protected coves and are

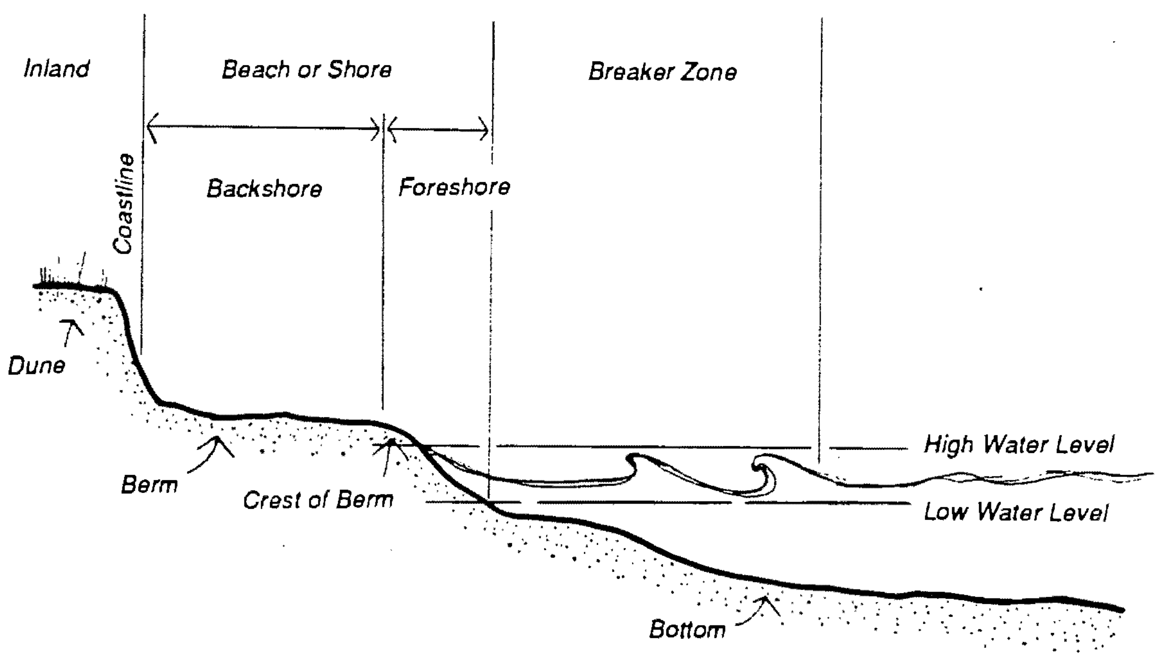


FIGURE 1: Shore Profile

SOURCE: *Low Cost Shore Protection*, Corps of Engineers, 1981.

completely submerged during high tides. In addition, some beaches have been created for recreational activity, such as Robert Crown Beach in Alameda and at Candlestick Point State Park in San Francisco. The long, flat slope typical of a beach foreshore, and the buildup of material normally deposited on beaches in summer also provide a natural defense to shoreline erosion, both as a sacrif.icial buffer between land and water, and by causing waves to break farther offshore (see Figure 1).

The shape, of the shoreline, offshore islands and rocks, and submerged topography also play an important role in the erosion process because such features alter the distribution of v/ave energy. For, example, headlands receive more concentrated wave energy than bays and inlets. As a result, structures projecting out from the shoreline usually require extra protection.

Wave motion, particularly .that of breaking waves, is the major force in both the erosion and the building of shorelines. The characteristics of waves are determined by wind speed, its duration and direction, the water depth, and the fetch. As waves break, run up the shore, and return, material is carried both onshore and offshore. The water's ability to move material is determined by its speed. Thus, large waves or strong currents can carry larger quantities and heavier material. Because waves generally arrive at an angle to the shoreline, material is transported along the shoreline in a series of zigzags. This process of moving material is called littoral drift (see Figure 2). The result of littoral drift is that material eroded from one location is carried and deposited at another location.

erosive processes are influenced by changes in water level and land subsidence, which expose new surfaces to erosion, as well as seasonal changes v/hich are generally accompanied by shifts in the severity and direction of both wind, currents, sea level, and waves.

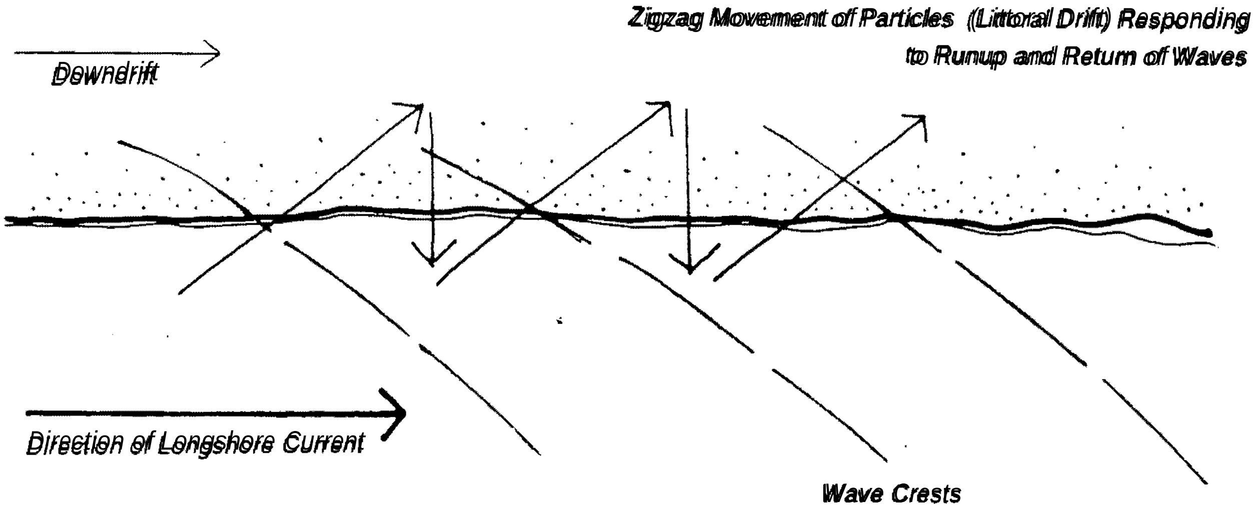


FIGURE 2: Littoral Drift

SOURCE: *Low Cost Shore Protection*, Corps of Engineers, 1981.

Human activity can also affect coastal processes. Installation of erosion control structures and other modifications of the shoreline, including construction of such facilities as marine terminals, marinas, levees, and bridges, can alter both littoral drift and redirect erosive forces. In addition, ship traffic can increase both the water level and wave action along shorelines. For example, propeller wash attributed to operation of the Larkspur Ferry has been alleged to have increased the erosion rate along the Corte Madera shoreline and the Tiburon Peninsula. In the Oakland Estuary, large vessels using the channel can displace sufficient water to both raise the water level and increase wave action along the shoreline. Dredging also affects wave activity as larger waves are generated in deeper waters. Actions of ships can also affect bottom topography. For example, large vessels typically drag anchors to improve control of the vessel when approaching a berth. Repeated many times at the same location, such action can deepen the area adjacent to the berth. Ships moored for an extended period can also cause shoaling, as occurs at the Moth Ball Fleet in Suisum Bay.

These coastal processes operate in all bodies of water. Although San Francisco Bay may not be subject to the same intensity of erosion that is experienced along open ocean coastlines, the Bay is subject to greater erosive forces than is generally perceived when looking at calm Bay waters. Most erosion occurs during winter storms and powerful, destructive storms have hit the Bay as recently as 1983.

Natural Defenses

The gently sloping shores of beaches, marshes, and mudflats cause waves to break offshore and lose a significant part of their energy -- a natural defense to the erosive force of waves. In addition, the roots and rhizomes (horizontal, underground stems) of marsh plants anchor the sediment while the above ground portions of the plants dampen waves and trap additional sediments. The next line of defense for upland areas fronted by beaches and marshes is the shoreline berm, the ridge or mound of material that has been deposited above the normal high tide line (See Figure 1). Berms prevent normal high water from moving further inland. In beach settings, dunes (a ridge or mound of loose, wind-blown material) offer the last line of defense against storm-driven high water, as well as providing material for rebuilding the beach. Dune plants serve to anchor and build dunes much as marsh plants work to hold and build the foreshore. The Army Corps of Engineers recommends that "erosion control should begin with protection of the natural shoreline defenses wherever possible." (U. S. Army Corps of Engineers, 1981e).

CHAPTER III.
CONTROLLING SHORELINE EROSION

There are three basic approaches to combating the problems caused by shoreline erosion: (1) reduce the impact of erosion by locating structures and improvements away from erosion-prone areas; (2) prevent or reduce wave attack on the shoreline by altering the prevailing coastal process, usually with offshore shoreline protection measures; and (3) protect the shoreline by hardening it to make it more resistant to erosion. This chapter discusses the various approaches for halting shoreline erosion that have been successful in the United States, their relative costs and effectiveness, and their environmental impact. Because hundreds of different structures and techniques have been used in the United States to protect shoreline areas, the following discussion is not, and is not intended to be, an exhaustive list of such devices and methods. Instead, this chapter highlights those structures and measures that have been successfully used, or have potential for successful use, in San Francisco Bay. A more comprehensive listing of shoreline protection measures, their relative costs, and an evaluation of their effectiveness, is presented in Appendix A.

The first step in designing and implementing any measure to protect shoreline property is to determine the prevailing coastal processes at work at the site. Such an evaluation must take into account not only the expected daily erosive forces at work at the site, but also the extreme conditions that may occur during exceptional high tide and storm wave conditions, such as those that occurred in San Francisco Bay during the winter of 1983. Because so many factors influence how erosion will act on a shoreline, an erosion, control structure or strategy that has been effective at one location may not be effective at another.

Second, it is important to recognize that protecting shoreline property in one area may accelerate erosion in an adjoining area by redirecting erosive forces of Bay waters and by interrupting or altering the natural flow of Bay water and sediments. For this reason, it is almost always more effective and economical to coordinate erosion control under a comprehensive plan that considers the erosive processes on a regional basis. However, this rarely happens because individual property owners typically propose individual projects for their properties.

It is also important to recognize that virtually all measures to protect nearshore property will fail in time. Although it may be theoretically possible to construct a long-lasting protective structure in an area subject to intense wave energy, such a structure would be prohibitively expensive. As a result, engineers design erosion control structures for a specified design life, typically a storm that, on average, will occur once every 15 or 25 years. But such a storm could occur the day the project is completed, causing extensive damage or complete failure of the protective structure. This design limitation led the authors of one study of coastal protection measures along the central California coast to conclude that:

> On the whole, few protective structures in the study area have stood the long-term tests of time, surviving unassisted and preventing damage and erosion, for more than twenty years or longer than their design life.

> Many structures have becoine structurally unsound, required considerable maintenance or repair, and/or failed to adequately reduce property damage for more than one severe storm period. Thus, the effective lifetime of a structure often depends on how many mild winters pass before the next severe storm. However, most of the structures have reduced erosion rates, at least over the short term (Fulton-Bennett and Griggs, 1986).

The factors that typically lead to the failure of protective structures are: overtopping, outflanking, scouring, piping, vertical forces, and floating debris and suspended materials.

1. Overtopping. Overtopping takes place when significant amounts of water move over the too of a protective structure. Overtopping damages the structure by eroding the support material behind the protective structure, and by exerting direct force on the protective structure itself as the water returns to the Bay.

2. Outflanking. Outflanking occurs when erosion exposes the ends of a protective structure and threatens both the structure and the material behind it. In an eroding shoreline, outflanking will eventually occur at all isolated, successful protective structures as material from neighboring, unprotected areas is washed away.

3. Scouring. Scouring takes place when underwater material is removed by waves and currents, particularly at the base or toe of a protective structure. Scouring undermines the foundation of the structure and can lead to rapid loss of fill behind a wall or structure, threatening the structure itself.

4. Piping. Piping occurs when the material behind the protective structure becomes so saturated with water that it becomes fluid and is pumped by wave action through holes under or through the protective structure.

5. Vertical Forces. The energy of waves and wave splash can exert powerful, vertical forces on a protective structure, particularly when the protective structure has a vertical face or adjoins moderately deep water. These vertical forces have lifted riprap (stones or concrete rubble laid together on an embankement to prevent erosion) and other rocks up to two feet across from the base of vertical walls and thrown them inland.

6. Floating Debris and Suspended Material. Floating debris, when hurled against a protective structure by waves, can significantly damage a protective structure. Similarly, suspended material such as sand and gravel, can abrade protective structures, particularly those constructed of wood.

Because of the complexity of the forces acting on a given stretch of shoreline, because erosion control at one location may accelerate erosion of adjoining areas, and because the effective life of a protective structure is often determined by its design, its component materials, and how it is installed, it is important that such structures are designed and constructed by engineers well versed in coastal processes.

Non-Structural Methods of Erosion Control

Non-structural erosion control methods include regulating land use in flood prone areas and rebuilding the natural defenses to shoreline erosion by restoring or creating marshes and beaches., Land use controls are typically designed to lessen tidal erosions impact on land improvements by directing all but necessary shoreline uses away from an eroding shoreline rather than preventing or retarding erosion. Beaches and marshes serve more to slow the rate of erosion rather than stop it and tend to be most effective in controlling erosion along low wave-energy coastlines.

1. Land Use Controls

a. Background. Coastal erosion can be accomodated simply by avoiding the problems caused by erosion, rather than attempting to prevent, halt, or retard it. Land use controls can reduce the need for shoreline protection by: (1) permitting only uses that need a waterfront site in areas subject to erosion; (2) allowing only uses that are temporary, inexpensive, or unaffected by flooding to occupy erosion-prone sites-; or (3) requiring structures that need not be located at the water's edge to be setback at a safe distance from the shoreline.

b. Effectiveness. Because land use controls are most effective along relatively undeveloped shorelines, they may be difficult to implement in many areas of San Francisco Bay where much of the shoreline has been developed. However, land use controls may be appropriate for new bayfront projects proposed for undeveloped tracts, or useful in areas' that experience rapid shoreline erosion, or where massive protective structures would be needed to prevent flooding from a rise in sea level. Land-use controls could also be implemented in developed areas by requiring shoreline set-oacks for all new or reconstructed facilities. Such a set-back requirement could prohibit development in erosion-prone areas, or could set aside sufficient upland area to act as a sacrificial buffer or allow the construction of possible future shoreline protection facilities without Bay fill.

c. Cost. The cost of implementing land use controls is dependent on land costs, the cost of replacing lost structures and uses, and the cost of building required shoreline protection facilities. For these reasons, the cost of implementing land use controls cannot be generalized but must be determined for each shoreline project.

2. **Vegetation**

a. Background. Vegetation has been used successfully to control erosion in low wave energy areas at some locations in the United States, but has only been used on an experimental basis for controlling shoreline erosion in San Francisco Bay (Newcombe et al, 1979). Marsh plants slow shoreline erosion in three ways: (1) the aerial portions of marsh plants form a flexible mass which dampens wave energy; (2) as wave energy is reduced, sedimentation is increased, thereby allowing dense stands of vegetation to become established which leads to a building of the foreshore, and in turn causes waves to break farther offshore; and (3) the roots and rhizomes (horizontal, underground stems) of the marsh plants add stability to the shore sediment. This mass of roots is particularly important in the winter when much of the aerial portion of the plants die back (Knutson and Woodhouse, 1983).

Dune and upland plants also retard shoreline erosion by anchoring shoreside sediments from the erosive effects of wind and storm-driven waves.

b. Effectiveness. Marshes are one of the most important elements in the natural defense of the land in natural settings experiencing mild erosive forces. Unfortunately, marshes usually only slow the rate of erosion, rather than stop it; moreover, marshes are relatively ineffective in protecting against major winter storms. In addition, marshes can only be established at sites 'where the elevation, tidal regime, exposure to wave action, and soil type are conducive to the growth of the desired vegetation. The effectiveness of vegetation in controlling erosion is also dependent on a plant species .growth rate and habitat - slow growing plant species, such as San Francisco Bay's native cordgrass Spartina foliosa, are generally less effective in slowing erosion then plant species that quickly become established. Thus, San Francisco Bay's native cordgrass species, which usually takes at least three years to become established In even the most favorable conditions; has thus far not proved effective in retarding erosion. Establishment of such slow growing'species as Spartina foliosa can be aided using temporary wave-stilling structures, such as breakwaters. In fact, the authors of the most extensive study of vegetation to control bank erosion in San Francisco Bay concluded that "California cordgrass is'suitable for stabilizing relatively sheltered areas... [but is not likely to be effective in stabilizing]...eroding banks in San Francisco Bay unless the plants are protected from waves." (Newcombe et al., 1979) As a result, in San Francisco Bay planting may be most effective in erosion control when .used in conjunction with other measures of shoreline protection and in areas experiencing little erosion.

c. Environmental Impacts. The establishment of a marsh has several beneficial environmental impacts. Marshes serve as valuable sources of primary production (the photosynthetic building of plant tissues upon 'which all consumer organisms are ultimately dependent), as habitat for many species of wildlife, as nursery grounds for fish and other aquatic life, and as a natural system for storing and recycling nutrients and pollutants. Once established, erosion control plantings function as natural marshes and eventually attract comparable animal communities (Knutson and VJoodh.ouse, 1983). Marshes are also one of the few erosion control measures that are natural in appearance, and as a result, are perhaps the most aesthetically pleasing of all erosion control stategies.

d. Cost. Erosion control plantings are among the least expensive or all shoreline protection measures, costing between $3 and $17 per linear foot of shoreline.

3. Beach Nourishment

a. Background. Beach nourishment projects involve placing sand on the shoreline to function as an eroding or sacrificial buffer zone. There has been at least one successful application of beach nourishment for shoreline protection in San Francisco 3ay--the restoration of Alameda Beach and the protection of Shoreline Drive in Alameda (Commission Permit No. 9-31).

b. Effectiveness. The useful life of a beach nourishment project depends on how quickly it erodes; thus, a rapid succession of severe storms can completely and rapidly eliminate the sand placed to nourish the beach. The rate of erosion is also dependent on the size of the sand grains--larger (and therefore, heavier) grained sand erodes more slowly than finer grained sand. In most cases, a single nourishment will not provide a permanent solution to the erosion problem and the beach must be periodically renourished to replenish sand washed away. In the case of the Alameda Beach project, both groins (a low, wall-like structure built perpendicular to the shoreline to trap littoral drift) and sand traps (holes excavated in the beach) are used to retain the sand that would otherwise wash away.

c. Variations. A variation of the beach fill is the perched beach (see Figure 3). Perched beaches combine a low breakwater or sill with sand fill so that the beach is elevated above the surrounding area. The perched beach provides a broad buffer zone against wave action while offering a potentially valuable recreation site. A filter cloth is typically used behind the breakwater and under the fill to prevent sand from escaping through voids in the sill. Perched beaches are suitable where offshore slooes are

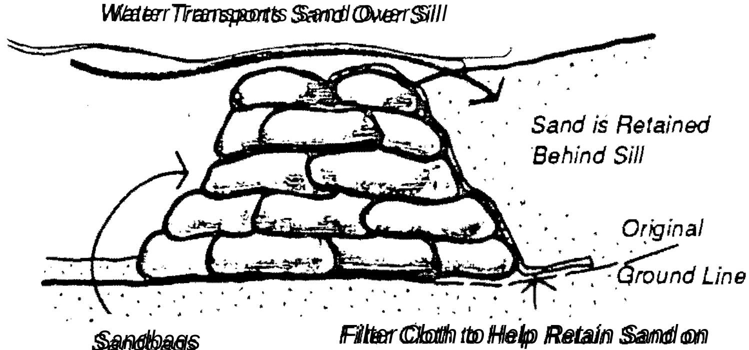


FIGURE 3: Perched Beaches

SOURCE: *Low Cost Shore Protection*, Corps of Engineers, 1981.

gradual enough so that the sill can be constructed offshore in shallow water and are appropriate where sand loss is too rapid for economical and convenient replenishment.

d. Environmental Impacts. Beach nourishment projects can serve as valuable recreation areas. Such projects can also benefit downdrift shore areas as littoral drift transports sand to them. But, as in the case of the Alameda project where the downdrift area was a tidal marsh, littoral transport of sand can lead to increased sedimentation in adjoining areas and a rapid change in their resource value. (In Alameda, a combination of sand traps and groins were constructed to capture sand that would otherwise migrate into the marsh). In addition, the sand placed to nourish the beach reduces the Bay's surface area and volume, and may cover intertidal mudflats which typically have greater aquatic animal and plant species diversity and productivity than sandy beaches.

e. Cost. Beach fills generally have low initial costs (approximately $50 per linear foot) but involve periodic maintenance costs (for replenishing lost sand and moving sand that has been deposited against groins or in sand traps) which increases the long-term costs of such projects.

Structural Methods of Erosion Control

Shoreline erosion is most commonly controlled by structural methods designed to either harden the shoreline against wave energy (generally revetments, bulkheads, and seawalls), or to alter prevailing coastal erosion processes (generally breakwaters, jetties, and groins).

1. Revetments

. a. Background. Revetments are protective, blanket-type structures that extend below low water and are built against the toe of a bluff or the face of an earth embankment. Revetments are by far the most common type of shoreline protection throughout the United States and in San Francisco Bay. They work by hardening the shoreline or by insulating the land from the erosive effect of waves. Revetments rest upon, and are supported by, the land behind it, which is usually at or near its natural angle of repose. Slopes steeper than one and one-half horizontal to one vertical are unsuitable for revetments unless flattened to a more gradual slope. The revetment must be built high enough so that it will not be overtopped, the sides must be protected from outflanking, the toe must be protected from scour, and a filter cloth or filter layer must be placed beneath the structure to aid drainage and help prevent settling and piping. There are many different kinds of revetments, the most common being rubble, quarrystone and concrete riprap, gabions, stacked bags of sand or concrete, and interlocking concrete blocks and mats (see Figures 4, 5 and 6).

b. Variations and Their Effectiveness

(1) Rubble revetments consist of loose dirt, concrete or asphalt slabs of varying sizes, bricks, and other construction debris dumped along the water's edge for shoreline protection. These revetments are often

used in emergencies and are generally very ineffective largely because their haphazard placement and sizing fails to protect the bank material underneath (Fulton-Bennett and Griggs, 1986). Usually such revetments quickly fail as the rubble flattens as it slides bayward. Although the initial cost of such revetments is usually low, the use of rubble may lead to unexpected future costs because it may have to be removed before constructing any long-lasting engineered protective structure at the site.

(2) <u>Engineered Quarrystone or Concrete Riprap</u> consists of carefully placed layers of different sized rock or concrete, an excavated or graded foundation, and filter cloth (see Figure 4). Riprap can be adapted to a variety of different shoreline conditions and is often used in combination with other shoreline protection devices. Quarrystone riprap has been reported

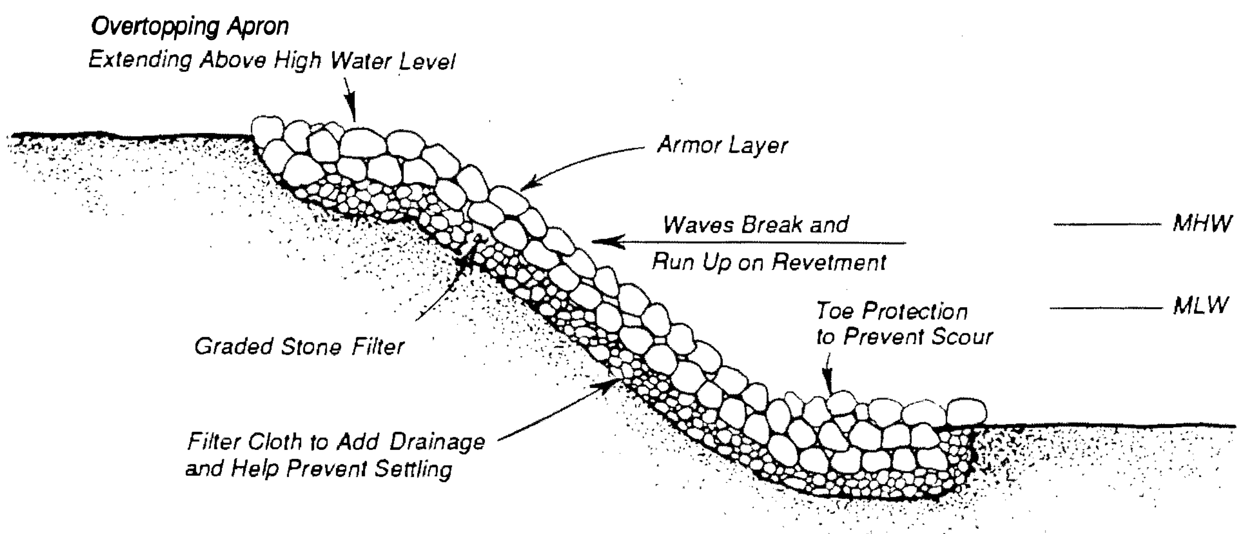


FIGURE 4: Typical Revetment Section

SOURCE: *Low Cost Shore Protection...a Guide for Local Government Officials*, Corps of Engineers, 1981.

to offer several advantages over other protective structures: (a) the rough surfaces of the rock and the spaces between the rocks help dissipate wave energy and reduce the extent of wave runup and overtopping; (b) its flexibility often allows it to settle and/or be damaged without experiencing massive or rapid structural failure; (c) it is easily maintained and modified; (d) it is resistant to damage by debris; and (e) it is relatively inexpensive to construct (Fulton-Bennett and Griggs, 1986). However, riprap placed on sand or other unconsolidated materials tends to settle into the loose material over time. Riprap revetments may also fail when wave action moves armor stones to another location of temporary stability, which can occur if undersized stones are used in the revetment, or during powerful storms. Dislodgment of armor stones is particularly a problem when riprap is placed on slopes steeper than one and one-half horizontal to one vertical, and when smooth, undersized, or flattened stones or concrete is used. Other typical causes of riprap failure include: scour at the toe of the riprap, fluidization of the foundation material, outflanking of the riprap revetment, inadequate revetment height, and vandalism.

(3) Gabions are rectangular mattresses of stones enclosed a wire mesh (see Figure 5). Gabions are flexible, retain some of their effectiveness even if the foundation settles, are easily repaired,, and can be built without heavy equipment. However, the wire mesh of the gabion is susceptible to damage by water-borne debris and abrasion by suspended sands, gravel, and the enclosed stones if they are not tightly packed. Rusted and broken wire baskets also pose a safety hazard (U. S. Army Corps of Engineers, 1981b).

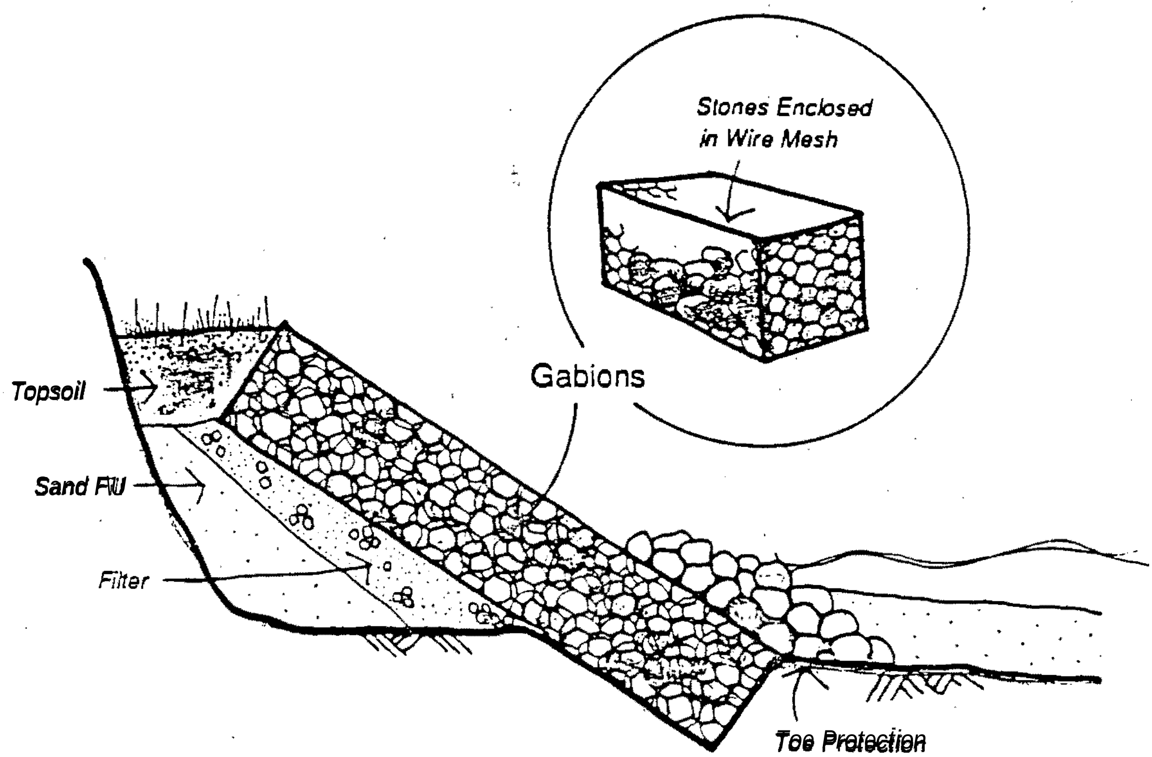


FIGURE 5: Gabions

SOURCE: *Low Cost Shore Protection*, Corps of Engineers, 1981.

(4) Bags, typically filled with either sand or concrete, are often stacked along an eroding shoreline for emergency protection. Stacked bag revetments are generally effective only in low energy areas, do not intermesh well because of their smooth surfaces and rounded corners, have a relatively short life, and are usually considered to be unattractive. In addition, since concrete-filled bags are rigid, any failure of one bag can lead to catastrophic failure of the entire structure through erosion of the foundation material (U. S. Army Corps of Engineers, 1981c).

(5) A variety of <u>interlocking concrete blocks and mats</u> (mats are revetments made of interlocking concrete blocks attached to a filter fabric or other material) have been developed for erosion control and many have proved relatively effective (see Figure 6). They all require a good, stable foundation and present a neat and clean appearance. Some have been

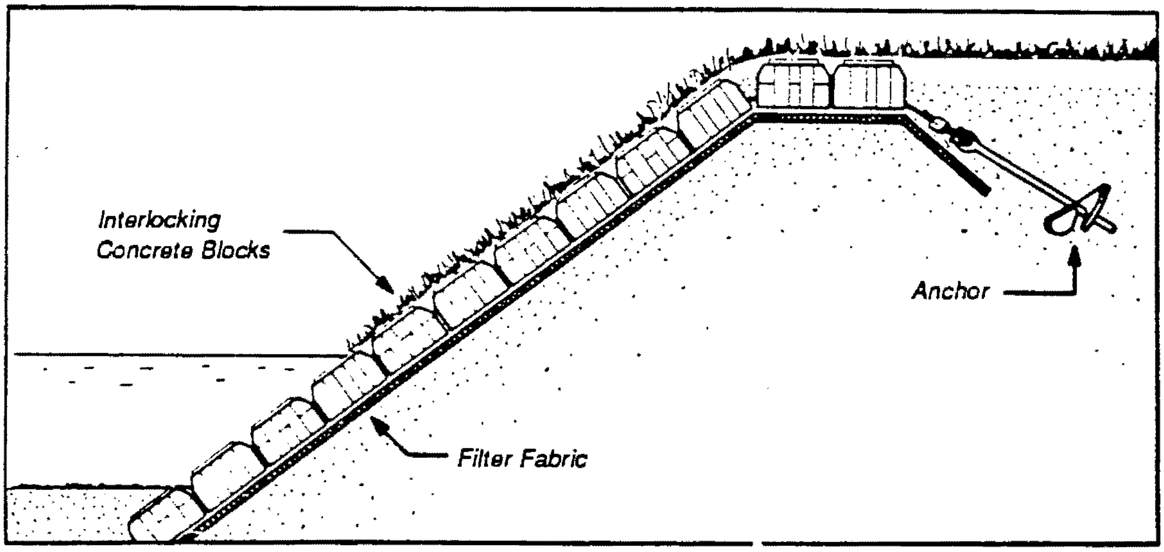


FIGURE 6: Profile of Typical Concrete Mat or Block Revetment SOURCE: Armortec, Inc., 1984.

designed to accommodate vegetation which may increase their stability. Such revetments have two major disadvantages. First, the interlocking between units must be maintained. Once one block is lost, other units can quickly become dislodged leading to possible catastrophic failure. Because most revetments settle differentially over time, this characteristic of interlocking block type revetments make them more susceptible to settlement problems than riprap revetments which tend to fold in on areas that have settled differentially. Second, the smooth face of such revetments allows greater wave runup which increases the possibility of overtopping.

c. Environmental Impacts. In natural settings, a revetment is a dramatic alteration in the shoreline, eliminating or modifying the intertidal zone covered. Because intertidal areas are one of the most productive areas of estuaries (Odum, 1970), revetments can result in many changes to the biota. The structure itself covers established flora and fauna and usually represents a major change in substrate. Thus the plants and animals that live among a revetment are typically quite different from the plants and animals that lived on the site previously. Revetments constructed in wetland areas can cover narrow fringe marshes leading some observers to describe wetland destruction as the "most significant ecological impact of riprap construction" (Carstea et al. 1975). In addition, revetments usually result in the destruction of transition edge habitats.

However, many organisms, including crabs, barnacles, mussels, and amphipods do live on and among the surfaces of revetments, particularly riprap. Occasionally, where riprap has been placed on a sandy beach— an environment typically poor in species diversity and productivity--the revetment has actually increased species diversity (U. S. Fish and Wildlife Service, 1980). In general, rough-faced and shallow-sloped revetments provide better habitats for aquatic and intertidal organisms than smooth-faced, steep-sided structures because they tend to dissipate wave energy better and because the rough-sided surfaces and hollows of such revetments provide a greater diversity of habitats for various organisms (Gantt 1975)

d. Cost. Rubble is generally free; its costs as a revetment is generally dependent on transportation and installation costs. However, rubble revetments have hidden long-term costs due to their high maintenance requirements.

The cost of quarrystone revetment depends on the size of the rock used, its availability, and the equipment needed to place it; it typically costs from $60 to $145 a linear foot.

Gabions, stacked bags and interlocking blocks and mats range in cost from $50 to $245 per linear foot (see Appendix A).

2. <u>Bulkheads and Seawalls</u>

a. <u>Background</u>. Bulkheads and seawalls have also been extensively used to harden shorelines against tidal erosion (see Figure 7). Bulkheads act both as retaining walls to prevent the land behind them from crumbling into the water, and as protection against waves. Seawalls are primarily designed to resist wave action and are usually massive, free-standing structures (U. S. Army Corps of Engineers, 1981c). The great disadvantage of vertical-faced bulkheads and seawalls is that the hard, smooth surface of the structure reflects wave energy, leading to accelerated erosion in front of the wall (scour). Because scour can erode both the foundation of the wall and the foreshore, an apron of heavy stones (riprap) is generally placed at the base of the wall to absorb the reflected wave energy. In

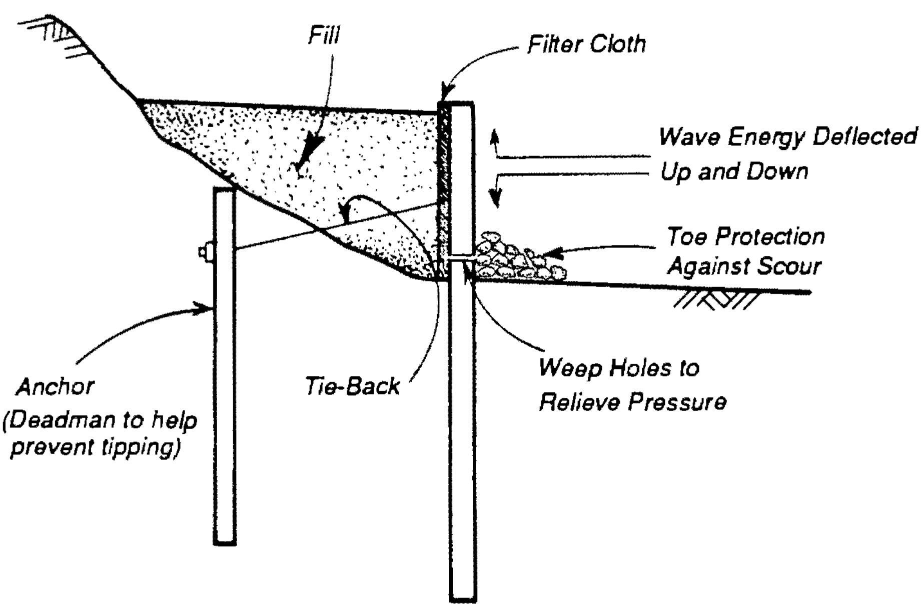


FIGURE 7: Typical Bulkhead

SOURCE: *Low Cost Shore Protection...a Guide for Engineers and Contractors*, Corps of Engineers, 1981.

addition, water overtopping such structures tends to flow laterally behind the wall washing away the fill behind the wall. Outflanking is another common cause of failure of such structures.

There are three basic designs of bulkheads and seawalls: (1) sheet pile walls consist of interconnecting or tightly spaced sheets of concrete, steel or wood driven vertically into the ground (additional support for these walls is sometimes provided by tying such structures to embedded anchors or by installing bracing on the seaward side); (2) post-supoorted walls consist of regularly spaced posts with attached facing. As with sheet pile walls, additional structural support is sometimes provided through anchors and bracing; and (3) gravity or free-standing walls rest on the ground and are supported by their own weight. Concrete, gabions, longard tubes (a large fabric tube filled with sand), and, rock and concrete rubble have all been used to construct free-standing walls. Variations of bulkheads have been designed or constructed in San Francisco Bay that attempt to incorporate provisions for marsh vegetation. For example. Commission Permit No. 13-37 (Bayview Drive, Alameda) authorized a protective structure (as yet unbuilt) consisting of a series of stepped bulkheads that would create terraces at suitable elevations and with suitable substrate for marsh establishment; along the Greenbrae Boardwalk in Larkspur, a resident constructed a wooden bulkhead, placed dredge spoils behind it, and then planted the spoils with native marsh vegetation to anchor the dredge spoils and reestablish marsh that had eroded away. Experience with such approaches is still too limited to determine their effectiveness.

b. Environmental Impacts. The major adverse environmental impacts of bulkheads and seawalls stem from the fact that such walls promote erosion of the foreshore by reflecting wave energy. The increased turbulence in front of these walls often prohibits vegetation from reestablishing on the foreshore, and has been suspected of producing less favorable conditions for the settling, growth, and survival of various benthic organisms such as clams, oysters, and shrimp (U. S. Fish and Wildlife Service, 1980). In addition, construction of bulkheads, like revetments, usually eliminates much of the intertidal zone, which is one of the most productive zones of estuaries (Odum, 1970).

c. Cost. Because of the tremendous variation in the design of these protective walls, cost per linear foot ranges from ^60 for a rubble mound wall to ^4000 for the 0'Shaughnessy Seawall along Ocean Beach in San Francisco, one of the most successful protective structures on record (Fulton-Bennett and Griggs, 1986).

3. Breakwaters and Sills

a. Background. In contrast to bulkheads and revetments, breakwaters and sills are placed offshore to intercept the energy of approaching waves before the waves reach land. Fixed breakwaters are built up from the estuarine floor using massive, heavy material such as rocks, gabions, concrete modules, car bodies, ships, sheet piling, sand-filled fabric tubes (Longard tubes), etc. Floating breakwaters are constructed of virtually any buoyant material, including rubber tires, logs, and hollow concrete modules. Sills are submerged, fixed breakwaters. Breakwaters and sills protect shorelines by intercepting waves offshore, creating a low-energy shadow zone on their landward side. The reduced wave energy also decreases the rate of ILctoral drift on shore and can induce sediment deposition, providing further protection to the shoreline.

b. Effectiveness. Breakwaters have been constructed in San Francisco Bay primarily to protect harbor areas, rather than for controlling shoreline erosion, although at one time both fixed and floating breakwaters were considered to protect, the shoreline from waves generated by the Larkspur Ferry. Floating breakwaters are generally only effective'in relatively sheltered areas experiencing mild wave action. Temporary floating breakwaters have been helpful in establishing marshes at locations where the wave action is too severe for plant establishment without some wave stilling device (Allen and v'Jebb, 198.3). However, there are three major drawbacks 'to floating breakwaters. First, they are generally ineffective in high v/ave energy areas For example, the floating tire breakwater at Pier 39 in San Francisco provided insufficient protection for its associated marina and had to be removed and replaced with a fixed breakwater. Second, floating breakwaters require significant- maintenance, both to correct the loss of buoyancy of component materials and to maintain the connections betv;een various components which are placed under considerable stress by wave action. Finally, it has often proved difficult to securely anchor floating breakwaters.

The effectiveness of fixed breakwaters and sills is largely determined by their size, the material used in their construction, and their placement in relation to prevailing coastal processes. Properly designed, they have proven quite effective in halting shoreline erosion. However, breakwaters and sills are both subject to scour. In addition, they may cause increased erosion in other areas, both because they focus and redirect wavs energy, and because they typically interrupt littoral drift thereby starving downdrift areas (United Nations, 1982). A local example of this is the loss of many acres of coastal property and portions of Highway 1 by redirected wave energy after construction of the Half Moon Bay breakwater in San Mateo County.

c. Environmental Impacts. Breakwaters and sills adversely impact the environment primarily by altering longshore littoral transport. The resulting accretion of sediment behind the breakwater typically leads to formation of seaward projection of the shore (a tombolo) which acts as a sediment trap, depriving downdrift areas of sediment. In addition, the interruption of littoral drift can lead to increased deposition of sediments in protected navigation channels, requiring further dredging and spoil disposal. Floating breakwaters and sills tend to have much less influence on littoral drift than fixed breakwaters (U.S. Army Corps of Engineers, 1973). Fixed breakwaters also cover areas previously inhabited by benthic (bottom dwelling) organisms. However, in many situations, the new rocky habitat created by the breakwater can be considerably more productive than the previous habitat, a fact well documented in the literature about artificial reefs (U.S. Fish and Wildlife Service, 1980).

d. Costs. The cost of a breakwater or sill will largely be determined by the wave climate and water depth of the proposed site, which in turn affects both the size, design, and maintenance needed for the breakwater to be effective. Thus, there is tremendous variation in the cost of breakwaters and sills. Typically, however, the breakwaters used for erosion control (as opposed to those constructed for harbor facilities) are small and range in cost from $30 to $1400 a linear foot (see Appendix A). However, such structures can have enormous offsite costs including loss of land by redirected waves, interruption of littoral drift to dov/ndrift areas, and increased dredging costs in navigation channels landward of the structure.

CHAPTER IV.
STUDY METHODOLOGY AND OBSERVATIONS

A primacy goal of this study was to evaluate the individual and cumulative impacts of the many small fills the Commission has authorized for shoreline protection. For this reason, only administrative permits have been investigated; erosion control measures authorized in major permits (typically larger projects evaluated in a public hearing) and in amendments to existing permits, have not been included in the study sample.

The files of all administrative permits issued from 1973 through 1987 were reviewed to determine; (1) the number of erosion control projects that have been approved; (2) the types and relative numbers of structures that have been used to protect near-shore property; (3) the linear feet of shoreline affected by such projects; (4) the amount of Bay surface area and volume that have been displaced by protective structures; and (5) the Bay resources impacted by erosion control projects. Because the information in the permit files was not collected with the goal of supporting this analysis, many of the values for length of shoreline and the area and volume of fill have had to be estimated. However, in most instances, enough information is available to make reasonably accurate estimates (± 25 percent) of these values.

Field evaluations were conducted of 41 percent of the project sites (71 of a total of 172 project sites) to help determine what Bay resources were affected by the authorized protective structures. Information from site evaluations is also the basis for determining whether the completed structure is still intact and functioning as authorized and whether it has affected adjoining areas.

Amount of Fill Administratively Authorized for Controlling Shoreline Erosion

For the ten year study period, 172 permits were administratively authorized for shoreline protection (approximately 17 per year), affecting approximately 32.9 miles of shoreline (172,700 feet, or an average of 3 1/3 miles each year), covering 41 acres of Say surface area (1,787,000 square feet, or an average of 4.1 acres of Bay surface area per year), and resulting in a loss of as much as 218,500 cubic yards of Bay volume (for an average of 21,350 cubic yards a year).* Projects were grouped according to size and shoreline protection type. Totals for these various categories are presented in Figure 8 and graphically depicted in Figure 9.

The first category includes administrative permits with Bay coverage of 10,000 square feet (0.23 acre) or more. There are 40 projects in this group affecting approximately 144,100 feet (27.3 miles) of shoreline, covering as much as 36.2 acres (1,576,600 square feet) of Bay surface area, with a loss of as much as 190,100 cubic yards of Bay volume. As is apparent from Figures 8 and 9, although these larger projects comprise only 23 percent of the total number of erosion control projects administratively authorized during the ten year study period, they account for 91 percent of all fill administratively authorized for erosion control.

Note; As explained earlier, most of the fill figures are estimates and are subject to an error of plus or minus 25 percent. The figures used here and throughout the report are the best estimates of the true value. The square foot coverage of the fill could be as little as 30.3 acres, or as much as 51.3 acres.

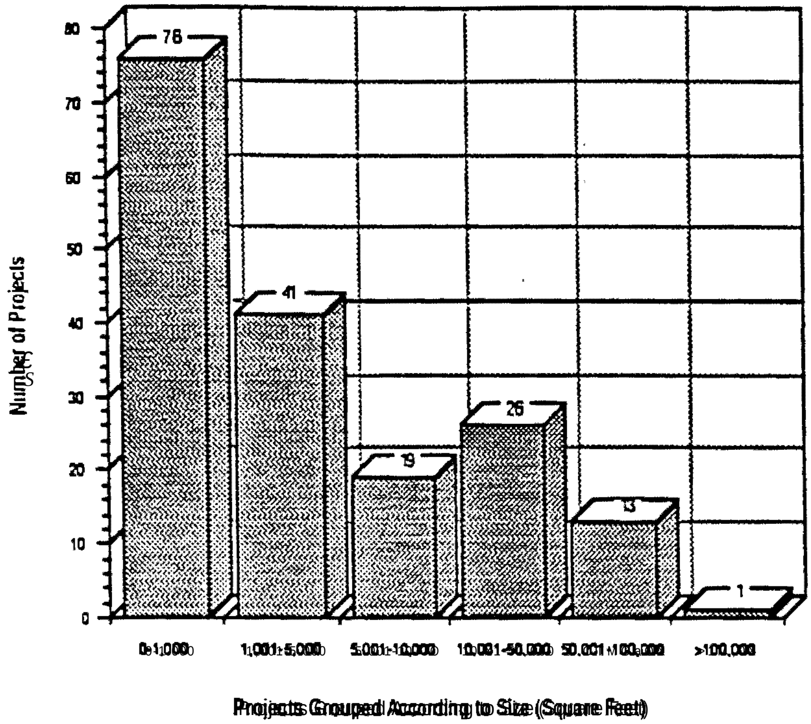
FIGURE 8

Amount of Fill
Authorized Administratively
for Shoreline Protection
1978-1987

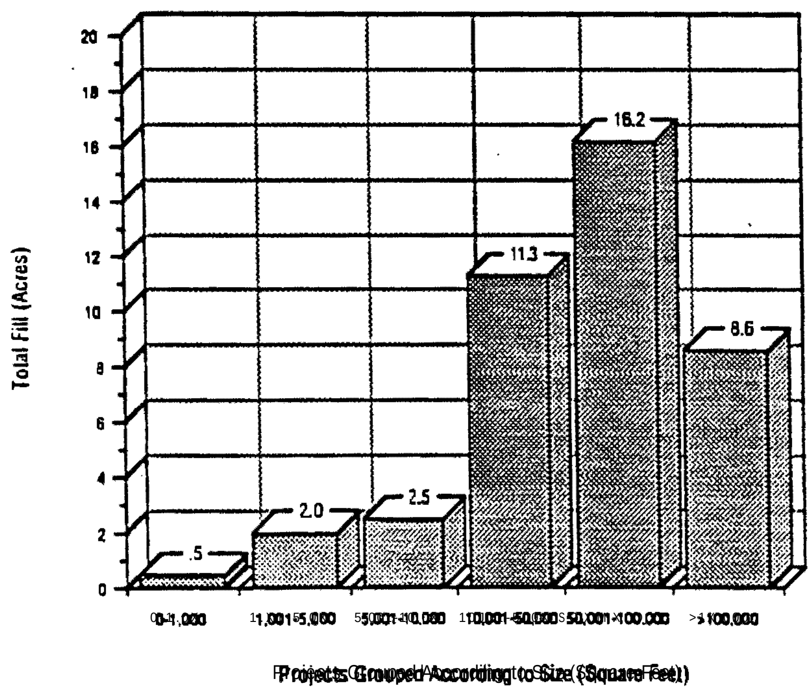
PROJECT		TYPE OF STRUCTURE	FILL DIMENSIONS		
Size	No.		Length (ft.)	Area (s.f.)	Volume (c.y.)
Admin. Permits covering 10,000 s.f. or more of Bay surface area	39	Revetment (typically riprap)	144,125	2,042,530	249,063
	1	Base of Wall (typically stones placed at the base of a structure to protect against scouring)	N/A**	59,602	4,415
Subtotal	40		144,125	2,102,132	253,478
Admin. Permits covering under 10,000 s.f. of Bay surface area	84	Revetment (typically riprap)	21,836	239,480	30,512
	20	Apron (various revetments)	676	19,488	1,403
	8	Base of Wall	1,387	13,634	1,477
	24	Bulkheads	4,635	8,095	3,550
Subtotal	136*		28,534	280,697	36,942
Total of all Admin. Permits	172*		172,659 (32.7 miles)	2,382,829 (54.7 acres)	290,420

* Four of the 172 administrative permits authorizing shoreline protection included construction of both a bulkhead and protection for the base of the bulkhead against scouring. These projects were counted twice - once as a bulkhead and once for base of wall.*

** Project consisted of toe protection at the base of the foundations for the Richmond - San Rafael Bridge.



a. Number of Projects Per Size Class



b. Total Fill Authorized Per Size Class

FIGURE 9:
Number of Projects and Total Fill
Administratively Authorized Per Size Class

SOURCE: San Francisco Bay Conservation and Development Commission, 1988.

The second category includes permits authorizing Bay coverage of less than 10,000 square feet (.23 acres). There are 136 projects in this group affecting approximately 5.4 miles (28,500 feet) of shoreline, covering as much as 4.8 acres (210,500 square feet) of Bay surface area, with a loss of as much as 28,400 cubic yards of Bay volume.

Figure 8 also groups projects employing similar shoreline protection measures. For administrative permits with Bay coverage of less than 10,000 square feet, 34 of the '136 projects (62 percent) involve riprapped slope protection, 20 (15 percent) are .concrete or rock aprons placed at the base of outfalls, eight (six percent) involve placing riprap in front and at the bass of walls and bulkheads, and 24 (18 percent) are bulkheads. Thirty-nine of the 40 permits (98 percent) with Bay coverage of 10,000 square feet or more involve riprap. In all, revetments of various types (primarily riprapped slopes and aprons) account for 83 percent of the shoreline protection projects administratively authorized by the Commission between 1978-87, and accounted for 97 percent of the Bay surface area lost due to efforts to protect shoreline property from erosion.

vOf the different types of protective structures, revetments, particularly riprap, involve the most fill in the Bay. Typically, fill for revetments involves both earth fill to prepare a suitable slope (at least 2 horizontal feet to 1 vertical, foot but often much flatter), and the revetment itself which can be up to several feet thick for areas subject to severe wave action. In contrast, most of the bulkheads and seawalls that have been built i,n San Francisco Bay have been either sheet pile v/alls or post supported walls (see pages 33-35 for description) which can be, and have been, built with much less fill.

Finally, the field investigations indicate that somewhat less fill has actually been placed in the Bay than has been authorized. Some of the projects have not been constructed (e.g. Permit No. M87-70 authorizing 34,000 square feet of riprap fill for the San Carlos airport) or involve temporary installations that have since been removed (Permit No. M78-9 authorizing 5,600 square feet of temporary riprap fill to protect Shoreline Drive in Alameda until installation of a permanent protection system). Also, although technically considered fill under the Commission's law, it is apparent that some erosion control projects involve placing fill in former upland areas that have eroded and become part of the Bay (Permit Mo. 12-74, Perry’s Restaurant in Mill Valley; Permit No. M84-10 shoreline along Lime Point Road, Fort Baker, Marin County).

CHAPTER V.
SHORELINE USES PROTECTED BY ADMINISTRATIVELY AUTHORIZED EROSION CONTROL STRUCTURES

Nearly all efforts to halt shoreline erosion involve some Bay fill. Under the Commission's law, the Commission can only authorize Bay fill if it determines that:

> ...the public benefits from fill clearly exceeds the public detriment from the loss of the water areas and should be limited to water-oriented uses (such as ports, water-related industry, airports, bridges, wildlife refuges, water-oriented recreation and public assembly...) or minor fill for improving shoreline appearance or public access to the bay....(Section 66605(a) of the McAteer-Petris Act).

Although most protective structures are authorized as minor fill for improving shoreline appearance, many protective structures protect land uses that benefit both the economy and the quality of life of the Bay area. To evaluate the public benefits of Bay fill placed to protect shoreline property from erosion, all 40 administrative permits authorized between 1978 and 1987 that involved more than 10,000 square feet (0.23 acre) of Bay fill for protective structures were analyzed to determine: (1) what kinds of land uses and improvements were protected by the authorized protective structures; (2) what public benefits were obtained from the fill placed to halt shoreline erosion; and (3) what, if any, economic analyses (ie. cost/benefit studies) was performed to justify the expense of the erosion control structure. Although these 40 projects comprised only 23 percent of the total number of administrative permits involving fill for protective structures, they accounted for 91 percent of all the fill administratively authorized to halt shoreline erosion.

Land Uses Protected by Erosion Control Structures and Their Public Benefit

Government agencies proposed 21 of the 40 administrative permits (52.5 percent) where more than 10,000 square feet of fill was involved to control shoreline erosion. All of these government-sponsored projects protected essential public uses and services and were either important to the economy and welfare of the Bay Area, or provided significant benefits to a local community. Examples of projects providing regionwide benefits include protecting the bridge supports of the Richmond-San Rafael Bridge (Permit No. M85-95 to Caltrans), the outfall, pipeline and dechlorination facilities for a major sewage pipeline (Permit Nq. M82-23 for protecting an East Bay Dischargers sewage discharge line), the San Mateo County airport in San Carlos (Permit No. M87-70), training facilities at the California Maritime Academy (Permit No. M85-39), the 220-acre restored tidal marsh in Hayward (Permit No. M78-128), and the popular beach at Robert Crown Memorial Park in Alameda (Permit No. M78-76). Other government erosion control projects, while perhaps of less regional significance, clearly provided important local benefits, such as protecting Emeryville's City Hall (Permit No. M85-45), and City streets, utilities, and residences (Permit No. M80-99 to the Town of Tiburon).

Nineteen of the 40 administratively authorized projects (47.5 percent) were proposed by private individuals or companies. Most of these privately-sponsored projects also provided important public benefits and protected substantial shoreline development and investments, which the

McAteer-Petris Act encourages (Government Code Section 66605.1). For example, seven of these projects (17.5 percent) were either in response to a government order to correct a water quality or enforcement problem, or to prevent water quality problems from occurring (e.g. Permit No. M85-69 to Levin Richmond Terminal Corporation to correct a toxic waste problem); two (5 percent) protected important regional transportation services (e.g. Permit No. M85-40 to Southern Pacific to protect a main line of the railroad^and Permit No. M78-14 to the Port of Benicia to protect port facilities); two (5 percent) protected public access facilities in addition to private uses (e.g. Permit No. M80-83 to the Bay Farm Island Reclamation District to protect residences and public access areas and M80-23 to the Dormer Corporation for protection of restaurants, shops, hotels, and a public promenade); one (2.5 percent) involved protecting a managed wetland in the Suisun Marsh (Permit No. M84-93(M)), and one (2.5 percent) involved protecting a site that, while vacant, has been designated by the Commission for future water-related industrial or port uses (M81-61(M) for the Collinsville site owned by the Southern Pacific Transportation Company).

Of the remaining six privately-sponsored shoreline erosion control projects, two (5 percent) protected residential communities (Permit Nos. M78-6 to the Edgerly Island Reclamation District in Napa County and M78-108 to Paradise Cay in Tiburon); two (5 percent) protected private recreational uses, including a private marina and a skeet shooting range; and two (5 percent) protected existing industrial/commercial developments in Vallejo (Permit Nos. M86-90 to General Mills to construct a new flour storage and blending facility and M80-34 to Manor Development for a truck stop and auto repair).

Figure 10 summarizes the land uses protected by these 40 administrative permits.

FIGURE 10
Shoreline Uses Protected By Administratively
Authorized Erosion Control Structures Involving
10,000 Square Feet or More of Bay Fill
1978-1987*

LAND USE	GOVERNMENT-SPONSORED	PRIVATELY-SPONSORED	TOTAL
Public Access	12	2	14
Landfill or Toxic Waste Site	2	7	9
Public Facility (e.g Bridges, roadways, railroads)	6	1	7
Residential	4	3	7
Industrial/Commercial	3	4	7
Marina or Recreation Facility	2	2	4
Vacant Property	3	2	5
Wildlife refuge or duck club	2	1	3
TOTAL	34	22	56*

* Forty administrative permits involving more than 10,000 square feet of Bay fill for erosion control were issued by the Commission between 1978 and 1987. Several of these projects protected more than one kind of shoreline use. Each kind of shoreline use protected by an erosion control structure is listed in this table, which is why the total is 56, not 40.

Cost/Benefit Analysis

Applicants are not required to provide information on the relative cost and expected benefits for any proposed project, so it is not surprising that none of the 40 administrative permit files examined included a cost/benefit analysis of the proposed erosion control structure. However, based on a review of the permit files and discussions with recent permittees, it is clear that in most instances, property owners simply determine that the value of the shoreline property and existing shoreline improvements easily justify whatever expense is necessary to halt shoreline erosion without performing a detailed cost/benefit analysis.

Similarly, few permittees had provided information on how their erosion control project would benefit neighboring properties, although a few projects ^ clearly protected areas well beyond the property boundaries of the permittee. For example, San Mateo County (Permit No. M87-70) stated in its application to install riprap along a levee face protecting the San Carlos Airport that:

> if the dike face is left unprotected the erosion will result in dike failure. This will result in flooding the Airport plus other low lying properties i.e.: Highway 101, Sam Trans Bus Yard and portions of Redwood Shores.

Detailed cost/benefit analyses may be performed for an erosion control project when: (1) the U. S. Army Corps of Engineers is considering doing the work; (2) applicants request funding assistance from the California Department of Boating and Waterways; or (3) an applicant is attempting to determine the most economical method of halting shoreline erosion.

A few permittees also suggested that the protective structure selected was determined by previous efforts at halting erosion along that particular shoreline. For example, riprap revetment was likely to be proposed for a shoreline that had previously been riprapped, albeit using state-of-the art materials and construction methods to extend the expected life of the structure.

CHAPTER VI.
IMPACTS OF ADMINISTRATIVELY AUTHORIZED EROSION CONTROL PROJECTS ON BAY RESOURCES

In most areas of San Francisco Bay, an eroding shoreline can threaten commercial, residential, industrial, and community facilities as well as agricultural uses and wildlife habitats. Private and public policy in the San Francisco Bay area has been to protect shorelines from receding inland and jeopardizing such uses. However, most measures to protect shoreline property involve work and placement of some fill in the Bay, for which a Commission permit is required, and which can displace or adversely affect Bay resources such as water surface area and volume, and bay habitats such as mudflats, marshes and transitional uplands. This chapter investigates how administratively authorized fills for erosion control have impacted San Francisco Bay. In particular this chapter addresses: (1) how such fills may be impacting Bay resources; (2) whether approved projects adequately protect shoreline property from erosion; (3) whether alternative erosion control measures exist that would better protect shoreline property while minimizing adverse impacts on Bay resources; (4) whether the Commission should require mitigation for proposed erosion control strategies; and (5) the practical . considerations in implementing changes to existing Commission practices.

Impacts on Bay Resources

Most literature on erosion control structures and strategies is engineering-oriented, focusing on the effectiveness of various approaches and how they affect erosional processes. Relatively little information is available concerning how such approaches affect the biotic environment. There is even less information concerning the cumulative impacts of many individual protective structures on a single system like San Francisco Bay.

Compounding this lack of information in the literature on the impacts of erosion control on plant and animal communities is the fact that, to date, applicants have not been required to provide information regarding the resources affected by their proposed project. As a result, few permit files include a specific description of the Bay resources impacted by the fill. However, slightly more than half of the 40 projects involving more than 10,000 square feet of fill for erosion control did contain either photographs or statements indicating that previous protective structures had been placed along the shoreline to protect property from erosion (for example, in Permit No. H85-40, Southern Pacific Railroad stated in its application for 8.6 acres of Bay fill to protect a mainline of the railroad that "the railroad has conducted basically the same maintenance procedure since the latter half of the 1800s').

Because protective structures typically cover whatever structure or resource pre-existed the fill, field investigations of the sites conducted in March through May 1988 did not determine with certainty what habitat existed prior to the placement of the protective structures. Nor can a single observation of a site yield more than limited information concerning the complex interrelationships of plant and animal populations that may have been affected by placement of protective structures. However, observations of project sites and adjoining areas provide some indication of whether the fill affected a subtidal area or intertidal marsh or raudflact. By speculating on the habitat that was likely covered or altered by construction of the protective structure, and using the best available information on the resource value of such habitats, staff qualitatively assessed what resources were likely impacted by authorized protective structures.

The field investigations suggest that nonvegetated, intertidal areas are the habitats probably most often impacted by authorized erosion control structures in San Francisco Bay. Of the 72 projects investigated in the field, 59 (82 percent) were constructed in such areas, including mudflats (the habitat most commonly affected), rocky cobble beaches, sandy beaches, and rocky intertidal cliffs and bluffs. Though they appear to be devoid of vegetation, the mudflats and other intertidal areas are among the most productive areas of an estuary, for they are significant sites of algal growth, they tend to concentrate organic detritus which break down and recycle important nutrients through the ecosystem, and they are a refuge for juvenile fish and invertebrates (Odum 1970). In fact, the California Department of Fish and Game (1979) has stated that "the San Francisco Bay mudflats are without doubt the single most important habitat on the coast of California for millions of shorebirds which breed in the arctic, and winter at this and more southerly latitudes."

Of the remaining 13 projects investigated in the field, three projects extended into subtidal areas (areas that are always submerged) and ten were constructed in areas bordered by either cordgrass or pickleweed tidal marsh.

In most instances, erosion control structures appear to be placed on shorelines that have already been significantly modified, either through earlier protective efforts, or past fill activity. Of the 72 permits investigated in the field, 57 of the projects (79 percent) involved protecting shorelines that already had been diked, filled, or protected. Only 15 projects (21 percent) had been authorized along shorelines that otherwise appeared relatively unaffected by previous human activity.

Finally, most erosion control projects, even those proposed on modified shorelines, cover and replace existing habitats, often changing them into something quite different. Even though much of San Francisco Bay's shoreline has been altered with dikes, protective structures, and solid fills, the area bayward of many of these fills and in some instances, the protective structure itself, supports intertidal mudflats, marsh vegetation, or sessile (attached) invertebrate communities. Because nearly all shoreline protection projects involve some construction outboard of the shoreline, new protective structures typically cover some intertidal habitat. Although various plants and animals live on and among protective structures, they tend to be different species than those formerly inhabiting the site. These plant and animal assemblages also tend to be less diverse and less numerous than their predecessors. Because mudflats and tidal marsh are the habitats most commonly displaced or affected by erosion control measures in San Francisco Bay, and because these habitats are highly productive, such alteration of habitat has probably decreased the total productivity of the Bay to some degree and may have diminished the Bay's ability to support the abundance of organisms that have historically lived in the Bay.

An important aspect of this change in shoreline character is that structures for erosion control not only occupy the narrow range of elevations that is suitable for marsh vegetation (when soil conditions and wave climate are suitable), but they also eliminate the transition zone between uplands and tidelands. To prevent problems of overtopping and wave runup, nearly all shoreline protection structures extend at least two or three feet above the line of highest tidal action into an edge habitat that serves as a refuge for animals at high tide, and as a seed source for recolonizing marsh areas.that are lost through erosion. These important functions.may be eliminated by construction of shoreline protection.

Effectiveness of Administratively Authorized Erosion Control Structures

Because the action of erosive forces differs for each site, it is difficult to compare the effectiveness of various protective,structures installed at different locations in the Bay. Similarly, since major storms play the most important role in the erosion process, it is not possible to compare the effectiveness of erosion control structures built at different times and thus subject to different storm conditions. Despite these limitations, field observations of the various types of structures indicate some differences in their performance.

Non-structural Methods of Erosion Control

Only one administrative permit of the 172 examined involved a non-structural method of erosion control*— Permit No. M78-76 to restore the

* Note: Non-structural methods of erosion control include regulating land use in flood prone areas and rebuilding natural defenses to erosion by restoring or creating marshes and beaches. See pages 21-26 for a discussion of these measures for protecting shoreline property from erosion.

beach at Robert Crown Memorial Park in Alameda. Although the maintenance requirements of this erosion control measure has been high (i.e. sand must be imported and redistributed to maintain the effectiveness of the beach for controlling erosion), the beach appears to effectively protect inland park facilities, a major thoroughfare, and adjoining residences.

Structural Methods of Erosion Control

1. Revetments. The term "riprap" has been used to describe a wide range of different revetments, ranging from rubble to engineered quarrystone. For riprap to be effective, it must include: (a) component materials that are durable, dense, and non-porous; (b) component materials that are correctly sized; (c) a design adapted to the site's soil and wave conditions; and (d) construction methods that assure careful placement of materials so that component pieces interlock with a minimum of voids. In San Francisco Bay, as elsewhere (U. S. Army Corps of Engineers, 1981a; Griggs, 1984; and Fulton-Bennett and Griggs, 1986), rubble revetments are often ineffective in preventing erosion because they typically fail to meet any of the four criteria necessary for successful protection. Revetments described as concrete riprap in Commission permits were usually rubble revetments consisting of haphazardly sized and placed materials. Often such revetments include materials that quickly wash away, such as dirt or asphalt, pose safety problems, such as rebar (steel reinforcing rods), or pollution problems, such as asphalt. Although rubble may slow erosion at some sites, it is apparent that rubble is fairly ineffective in preventing erosion over the long-term, primarily because wave action continues to work at the embankment through the

voids in the rubble, and because rubble revetments rapidly flatten to a very low angle of repose, exposing the bank to continued erosion, covering additional intertidal habitat, and displacing additional Bay volume. Even concrete rubble revetments where the concrete armor stones have been broken into graded sizes are less effective than quarrystone revetments, apparently because many of the component pieces are derived from large, smooth concrete slabs that do not interlock well even when broken, and which are easily dislodged by wave action because they present a large exposed area relative to their weight.

Using inappropriate construction material was not the only reason some observed riprap revetments fail, however. Some riprap projects consist of little more than dumping a few rocks on a slope. In these cases, the revetment fails because undersized material is haphazardly placed. As a result, the armor stones now lie offshore, providing little or no shoreline protection and covering valuable intertidal mudflats or marshes (e.g. Permit No. M85-1, rock riprap at Blackies's Pasture, Tiburon).

In contrast, many of the carefully designed and constructed engineered quarrystone revetments and aprons appear to be performing well in slowing or halting shoreline erosion while remaining in place (e.g. Permit No. M81-38 authorizing 2,800 linear feet of riprap to protect the northwestern approach to the San Mateo Bridge and M78-143 authorizing 2,500 linear feet of riprap along Richardson Bay Park in Tiburon). Because erosive factors differ from site to site, some of these effective riprap projects employed thicker revetments and larger stones than sites experiencing less erosion. However, problems are apparent even for these well designed revetments. Many of the quarrystone revetments were placed on previously riprapped slopes, a reminder that the life expectancy of all erosion control measures is limited and that protective structures must be maintained if they are to remain effective. In addition, as indicated by the rocks scattered bayward of these revetments, all of the observed quarrystone revetments had lost some armor stones over time. As with rubble revetments, quarrystone revetments tend to flatten or slump over time, although not to the same degree as rubble revetments. Such revetments also tend to settle when placed on Bay mud, as was observed in Sausalito where an apron constructed at the end of a discharge pipe had almost entirely disappeared beneath the Bay mud (Permit No. M81-62).

Field investigations were conducted of other revetments as well, but unfortunately, the sample size for these other structures was too small to drawn conclusions regarding their performance.

Only two gabion revetments had been administratively authorized in the ten year study period. Both appeared to be performing well— there was relatively little erosion landward of the gabions and there was no obvious dete^rioration of the wire mesh which enclosed the stones, and only slight separation between adjacent gabions. Both sites exhibited toe scour, however, with loss of foundation material along the bayward edge of the gabions and a resulting slumping bayward of the gabions.

No interlocking concrete blocks or mats had been authorized during the ten year study period and the effectiveness of the one observed stacked bag revetment was difficult to evaluate because the shoreline property had been further protected by construction of the beach nourishment project mentioned earlier.

2. Toe Protection. Field observations were made of three of the eight administrative permits authorizing toe protection at the base of a wall. toe protection in each instance consisted of large stones piled against the wall base. In all three cases, the 'toe protection had only been recently placed (that is, within the last three years) and there was no obvious indication of recent toe scour or other developing problems.

3. Bulkheads and Seawalls. Eight of the 24 administratively authorized bulkheads and seawalls authorized between 1978 and 1987 were visited. Unfortunately, only four of these eight bulkheads were in place at the time of the field investigations (one was a temporary bulkhead, since removed and three have not been constructed). The four bulkheads examined included two bulkheads, one seawall, and one breakwater, all of which seemed to be intact and performing well, although only the breakwater had been in place for more than two years. However, in the course of investigating different sites, particularly along Old Bayshore in Burlingame, several wooden, post-supported bulkheads that predated the study period were observed to have totally failed.

Alternative Erosion Control Measures

Chapter III discusses the types of erosion control structures and strategies that have been used to control shoreline erosion throughout the United States, which are further detailed in Appendix A. As indicated in this chapter, revetments, particularly rubble and engineered quarrystone riprap, have been the most widely used method of controlling shoreline erosion in San Francisco Bay, with bulkheads and seawalls used to a much lesser extent. There has been little experience in San Francisco Bay with other measures to control shoreline erosion. Because quarrystone riprap and concrete rubble involve fill in the Bay, displace Bay volume, and typically occupy intertidal mudflats that have important habitat value, an obvious question is whether alternatives exist that may afford similar protection to shoreline property with less adverse impacts on Bay resources.

Clearly natural defenses, such as planting native vegetation, offer an environmentally sensitive alternative to revetments. But as discussed in Chapter III, such plantings have been largely unsuccessful in San Francisco Bay for erosion control except in very low wave-energy areas where the soil provides the required stability for the plants and where weather conditions are amenable to sustained plant growth. However, in such low wave-energy climates, vegetation can be effective in slowing erosion, particularly if wave-stilling devices, such as breakwaters, are used to help the plants become established initially. Similarly, protective structures that incorporate provisions for marsh vegetation in the structure itself, as in Permit No. 13-87 (Bayview Drive, Alameda) where a series of stepped bulkheads will create terraces at suitable elevations and with suitable substrate for marsh establishment, or mat revetments of interlocking concrete blocks with space for vegetation, may provide effective protection for shoreline property and create suitable conditions for tidal vegetation. To date, however, such approaches are unproven.

A primary reason plantings have been ineffective in slowing erosion in San Francisco Bay is that most experiments have used the Bay's native cordgrass species. Spartina foliosa, which grows relatively slowly and takes several years to become established on a site. In the Suisun Marsh and in tributaries to the Bay with greater freshwater influence, other plants, such as common tule (*Scirpus acutus*) and alkali bulrush (*Scirpus robustus*) occupy the same zone as cordgrass but grow much more vigourously. In these regions of the Bay, erosion control with vegetation may prove to be more effective.

Land use controls, such as requiring structures to be setback a safe distance from a rapidly eroding shoreline, are also an environmentally sensitive means to avoid the problems caused by erosion and are being employed increasingly throughout the United States (Florida, North and South Carolina, New Jersey). Land use controls may be difficult to implement in San Francisco Bay where much of the shoreline has been developed, but may be appropriate for new shoreside developments proposed for undeveloped tracts, or in areas that are experiencing rapid shoreline erosion.

Beach nourishment projects and perched beaches (see pages 25-26) may also prove to be an effective alternative to revetments, especially where a recreational beach is desired. However, beach fills and perched beaches often involve more fill and greater reduction in Bay volume than other protective measures, and although intially inexpensive, require continual maintenance to maintain their effectiveness.

Despite the promise of these alternative protective measures to both control erosion and promote the Bay's natural resources, these approaches are still largely experimental. It is far too early to judge the long-term effectiveness or desirability of such approaches, or to require such approaches in all erosion control projects. Indeed, it is unlikely that these alternatives will be effective in all situations because their effectiveness will be determined in large degree by site characteristics. For example, the success of marsh planting depends on the elevation, tidal regime, slope of the site, exposure to wave action and soil type. Not all locations or physical conditions in the Bay will be conducive to marsh growth.

Mitigating the Adverse Environmental Impacts of Erosion Control

Most erosion control structures involve some fill in the Bay. As a result, they all have certain unavoidable adverse impacts on Bay resources. These adverse impacts include reducing Bay volume and surface area, altering tidal circulation, and changing the substrate, which in turn affects an area's animal and plant life.

Improving the design of protective structures can lessen some of these adverse impacts. Well-designed protective structures are less likely to fail, and, because additional fill is usually needed to repair failed structures, will require less fill over time than protective structures that have not been designed for the site's conditions. For riprap revetments, careful design improves the likelihood that armor stones will be correctly sized for expected wave conditions, and that the revetment slope is appropriate for the soil and wave conditions of the site, thereby reducing the likelihood that the armor stones will be washed offshore where they continue to displace Bay volume and affect wetland habitat. Similarly, a well-designed bulkhead or seawall should be constructed of concrete formulated for salt water and oriented so that reflected wave energy will not be focused on adjoining properties which would create additional erosion problems.

However, assuring that all erosion control structures are well-designed has implications for applicants and the Commission. Because of the complexity of the factors affecting erosion along a given reach of shoreline, the effectiveness and longevity of protective structures is greatly improved if they are designed and constructed by engineers with expertise in coastal processes. Having a coastal engineer design a protective structure would cost an applicant between ^2,500 and ^8,000 for a single-family residence with 100 feet of shoreline frontage, and between $4,000 and $15,000 for protecting commercial property with 300 feet of shoreline. Construction costs may also be higher for well-designed structures, which may involve more extensive work and more costly materials than would have otherwise been used. Although well-designed structures may be initially more expensive, they are likely to be more economical in the long-term because of.their improved effectiveness and reduced maintenance requirements.

Projects not designed by coastal engineers could be improved through plan review by the Commission staff. However, even cursory review and feedback to assure use of state-of-the art design and materials would take between .2 and .3 person years of staff time for the approximately 17 administrative permit applications received each year. This additional work could be accommodated only by adding staff resources or redirecting existing staff from carrying out current responsibilities.

Some adverse impacts to the Bay can be reduced simply by prohibiting use of certain materials in protective structures. In particular, eliminating the use of rubble for revetments will reduce fill in the Bay. In order for any revetment to be effective, it must be constructed of component materials that are durable, dense and non-porous. The component materials must be sufficiently heavy so they will not be dislodged by waves. The revetment must be designed in accord with the site's soil conditions so that it will not rapidly settle into the underlying substrate, and carefully constructed so that component pieces interlock with a minimum of voids. In most cases observed in San Francisco Bay, rubble riprap revetments typically fail to meet any of these criteria. The advantage of such revetments is that they are initially inexpensive to build, afford some temporary protection, and offer a place to dispose construction debris. And, in certain coastal areas, where the concrete rubble has been carefully sized and placed, such revetments have performed similarly to engineered quarrystone riprap. But the unsorted and unsized construction debris which typically make up such revetments often include dirt, wood, and asphalt materials that are quickly washed away. The concrete used is not formulated for use in sea water and has already gone through some period of weakening and deterioration. In addition, most pieces are slab-like in shape, presenting a large surface area relative to weight. Such slabs are moved more easily by wave forces than a more equally dimensioned shape of the same weight (United Nations, 1982) and do not interlock well. Finally, these rubble revetments are usually simply dumped along the shoreline with no consideration to settlement problems or elimination of voids. As a result, these projects rapidly become ineffective in preventing erosion, usually slide bayward, and often deteriorate to the point that they change the surrounding substrate from mudflat to cobble. Typically the solution has been to dump more material (United Nations, 1982), a solution which leads to increased fill in the Bay.

However, prohibiting use of rubble from being used to protect shoreline property will have implications both for future applicants and the Commission. Rubble is widely used in the Bay for revetments because of its low initial cost in comparison to other erosion control structures such as engineered quarrystone revetments which can cost as much as ^750 a linear foot. Prohibiting all use of rubble in shoreline protection may preclude some landowners with limited funds from protecting their property. As discussed in Chapter IV, many of the land uses that could be affected provide important public benefits, such as duckclubs, park districts, and wildlife refuges. Even for those uses that provide limited public benefits, it may be seen as unreasonable to prohibit an affordable means of protecting threatened property.

Prohibiting use of rubble might increase the Commission s enforcement case load, as some landowners might take any available measure to protect their property from erosion, particularly in emergencies. Because of staff and funding limitations, enforcing these violations would probably be at the expense of other necessary enforcement activities. Increasing staff review of concrete rubble revetments to assure that the concrete rubble meets performance s.tandards would involve between .1 and .2 person years of staff time.

Improved maintenance would also reduce adverse environmental impacts simply by better assuring that approved structures remain in place and function as authorized, thereby eliminating the need for additional fill to rebuild failed protective structures. Requiring that protective structures be regularly maintained would probably have negligible impacts on permittees, although such a requirement would increase the longevity of protective structures, thereby reducing long-term costs. Impacts on Commission staff would also be modest, although some time would have to be spent to monitor such permit conditions.

A more difficult question is whether mitigation should be provided to offset the adverse individual and cumulative impacts of fill placed to protect shoreline property. The impacts of shoreline protection projects on Bay resources are probably similar to the impacts of other fill where the Commission has required mitigation. For example, the Sewerage Agency of Southern Marin created a small tidal marsh and enhanced an existing marsh as mitigation for placing fill to expand and improve an existing sewage treatment facility in Mill Valley (Permit No. 21-80), a project having important public benefits, but with adverse impacts similar to those associated with protective structures.

The scarcity of suitable mitigation sites in the San Francisco Bay area, and the need to accommodate landowners who wish to take reasonable means to protect eroding shoreline property, must affect any policy to require mitigation for shoreline protection projects. Eroding shorelines often require immediate attention to prevent further losses. Further, as this study demonstrates, a small percentage of projects are responsible for nearly all of the fill administratively authorized for shoreline protection. In addition, many of the shoreline sites which are being protected from erosion are being used for activities that are of regional or local importance. Finally, it is proving to be increasingly difficult to find suitable sites for mitigation projects within the urbanized Bay Area. For all these reasons, it may be unreasonable to delay authorizing small shoreline protection projects until suitable mitigation programs can be initiated.

Because of the difficulty of finding suitable mitigation sites of any size in the San Francisco Bay area, and because of the expense of returning sites to tidal action, mitigation banks, or a "fill tax" where applicants contribute funds on a pro-rata basis toward the cost of acquiring, restoring, maintaining, and monitoring a new wetland, offer perhaps the most practical way for applicants proposing small amounts of fill to offset the fill's impacts. Unfortunately, the two mitigation banks proposed for the Bay area have both failed (see the staff report on Commission Mitigation Practices, March 1987, for a fuller discussion of mitigation banks in San Francisco Bay). And the concept of a "fill tax" has previously been considered and rejected by the Commission.

Yet, as described earlier in this chapter, small fills for protecting shoreline property are probably having a cumulative adverse impact on Bay resources. To offset the individual and cumulative impacts of administratively authorized erosion control structures, the Commission should consider the three following approaches:

1. The Commission could continue its existing practice of not requiring mitigation for administratively authorized erosion control projects. The Commission could determine on a policy level that the benefits derived from protecting existing shoreline uses, which are often in the public's interest, are sufficient to offset the detriment of the fill. The fact that the majority of protective structures are proposed for shorelines that have been previously protected, significantly modified, or newly eroded suggests that such fills may have minimal impacts on Bay resources.

The difficulty with this approach is that other projects also in the public interest (such as sewage treatment plants. Permit No. 21-80; landfill closure. Permit No. 17-82; bridges, Permit No. 20-73; and ports. Permit No. 8-78) and having impacts similar to those of shoreline protection have been required to provide mitigation. A question of equity is raised if projects to control shoreline erosion are treated differently. Continuing existing practices would have no impact on staff resources.

2. Recognizing that over the past ten years, 41 acres of Bay fill have been authorized administratively for erosion control, the Commission could determine that the cumulative adverse impacts of small erosion control projects outweigh the public benefits of these projects. Therefore, the Commission could decide to handle all future applications for shoreline protection projects as major applications to determine whether the benefits of the project outweigh its detriments and to decide whether mitigation should be required. Because about 15 to 20 erosion control projects are authorized administratively each year, this approach would result in the Commission handling an additional 15 to 20 major permit applications annually. The Commission’s current major permit workload is about 15 to 20 projects each year. Thus, this approach would result in about a 100

percent increase in the Commission's major permit workload, which would require an additional three to four permit analysts to process. Clearly, this approach would not be feasible unless the Commission s budget is substantially augmented.

3. Recognizing that the majority of administratively authorized fill for erosion control projects is the result of a small percentage of larger projects, the Commission could create a two tier system for evaluating protective structures: small erosion control structures (e.g. those involving less than 10,000 square feet of fill or .23 acres) could continue to be processed administratively and not be required to provide mitigation; erosion control projects involving more than 10,000 square feet of fill (.23 acres) could be evaluated by the Commission at a public hearing to determine whether mitigation should be provided in accord with the Commission's existing mitigation policy. This approach would concentrate staff and Commission efforts on the projects that are responsible for 91 percent of the administratively authorized fill for erosion control. As typically only 4 administrative permit applications per year propose 10,000 square feet or more of fill for protecting shoreline property from erosion, these applications could be analyzed in more detail to improve design and assure that possible adverse impacts are mitigated with modest changes in staffing.

Such an approach would raise questions of equity, i.e. smaller fill projects would be treated differently from larger fills for erosion control. The Bay would probably continue to shrink by approximately .6 acre per year as a result of unmitigated fill for erosion control. Finally, the best way to effect such a change in Commission procedure would be to amend the Commission's regulations, a difficult and time-consuming process.

Whichever of the previous options is taken, the Commission could also direct the staff to begin work on establishing a regional program of mitigation banks. These mitigation banks would be supported through funds collected on a pro-rata basis from applicants proposing Bay fill for erosion control, as well as from other applicants proposing fill for other approvable purposes. Mitigation banks offer the advantage of assuring that all fill applicants are treated equitably. Additionally, mitigation banks can eliminate the lag-time between habitat loss and habitat creation if the mitigation site is restored prior to project construction. Besides providing a ready source of off-site mitigation for erosion control projects, mitigation banks would be available for contributions from other projects proposing approvable fill, thus solving the worsening problem of finding any suitable mitigation sites in San Francisco Bay. This proposal would increase the cost of protecting shoreline property, but until a mitigation program is in place, it is impossible to determine how much each permittee should be charged.

CHAPTER VII
CONCLUSIONS

This study of administratively authorized minor fills to protect eroding shoreline property, and the literature concerning existing and experimental strategies and methods for protecting shoreline property from erosion, support the following conclusions:

1. Erosion control projects are needed to protect important shoreline improvements. The McAteer-Petris Act provides that "certain water-oriented land uses along the Bay shoreline are essential to the public welfare of the bay area" and that the Bay Plan should provide suitable locations for these priority uses. Moreover, the Act provides "that in order to make San Francisco Bay more accessible for. the use and enjoyment of people, the bay shoreline should be improved, developed and preserved..." through public and private initiative and investment. .Because so much of the San Francisco Bay shoreline is urbanized, erosion control projects serve an important purpose in protecting valuable and costly development from being damaged by wave action. In addition, many erosion control projects protect important public uses and services which benefit the public of the Bay Area.

2. Most erosion control projects involve some Bay fill. Typically, protective structures are built bayward of the existing shoreline, thereby impacting such Bay resources as water surface area and volume, tidal circulation, and wetland habitat.

3. Between 1978 and 1987, approximately 41 acres of Bay fill has been administratively authorized to control shoreline erosion. For the ten year study period, 172 administrative permits for controlling shoreline erosion

have been authorized, affecting approximately 33 miles of shoreline (approximately 173,000 feet), displacing approximately 218,000 cubic yards of Bay volume, and covering approximately 41 acres of Bay surface area (approximately 1,787,000 square feet). In comparison, the Commission approved 148 acres of fill for all major permits and consistency determinations over the same 10 year period.

4. A few large projects account for most of the Bay fill administratively authorized for erosion control. Forty (23 percent) of the 172 protective structures administratively authorized between 1978 and 1987 involved 10,000 square feet or more of Bay fill and accounted for approximately 36 acres (88 percent) of the total authorized fill for controlling shoreline erosion. The remaining 132 projects (77 percent) required a total of approximately five acres of fill, or approximately 12 percent of the total fill authorized for erosion control.

5. Fill for erosion control structures often alters Bay resources. Besides displacing Bay volume and reducing Bay surface area, erosion control structures usually cover nonvegetated, intertidal areas (usually mudflats) typically having important wildlife values.

6. Protective structures are both more effective and less damaging to Bay resources when they are well-designed, carefully constructed, and regularly maintained. Because factors affecting erosion vary for each site, no single protective structure or strategy is likely to be effective in all situations. When a structure is not properly designed for the site's unique conditions, it is more likely to fail, may require further Bay fill to repair, may have higher long-term costs because of the need for more frequent repairs, and may lead to greater disturbance and displacement of the site's Bay

resources. In mild conditions, even poorly designed structures will likely afford some protection. But the arrival of severe storms will typically lead to rapid failure of many protective structures, including well-designed ones that have exceeded their design life or have not been properly maintained. For this reason, protective structures must be continually inspected and repaired to ensure that their integrj.ty is maintained.

7. Erosion control strategies that protect or enhance Bay resources (e.g. land use controls or marsh creation) are typically only effective in areas experiencing mild erosional pressures. However, in some instances, it may be possible to combine marsh restoration with structural approaches to control shoreline erosion and promote Bay resources, for example, by using temporary wave stilling devices (such as floating breakwaters) or by creating areas within a protective structure that are suitable for marsh establishment. Protective structures that are more effective in protecting shoreline property in moderate to severe wave conditions generally have unavoidable adverse impacts on existing Bay resources (beach nourishment, revetments, bulkheads, seawalls, breakwaters, and sills).

8. Mitigating adverse impacts of erosion control structures has implications for applicants and the Commission. Assessing all erosion control projects to determine their environmental impacts and to determine suitable mitigation could only be accomplished by adding staff -resources or redirecting existing staff. As it is proving increasingly difficult to find' suitable sites for mitigation projects within the urbanized Bay, requiring mitigation for small erosion control projects would probably lead to delays in protecting shoreline property, and increased costs to applicants.

9. <u>Rubble is ineffective in halting shoreline erosion and may lead to increased fill in the Bay.</u> Rubble, typically consisting of loose dirt, concrete or asphalt slabs of varying sizes, bricks, and other construction debris, provides some short-term protection, but often quickly fails as the rubble slides bayward or is washed offshore. To maintain protection of shoreline property, additional rubble is typically placed along the shoreline, leading to increased fill in the Bay and continual disturbance to Bay resources.

CHAPTER VIII
RECOMMENDATIONS

Under the McAteer-Petris Act, the Commission must balance protecting the natural resources of the Bay with encouraging appropriate development of the Bay and shoreline. This balance is perhaps nowhere more difficult to achieve than where property is threatened by shoreline erosion. As yet, there is no approach which both effectively prevents shoreline erosion and protects existing Bay resources from moderate or severe wave action, although marsh creation may slow erosion in low wave energy environments. Thus, the Commission is often placed in the difficult position of having to choose whether to protect natural resources at the expense of allowing shoreline property to be eroded, or to authorize protective structures that may damage Bay resources. The results of this study suggest that this inherent conflict can at least be partly resolved by implementing measures that: (a) improve the information provided by applicants concerning how such projects will impact Bay resources; (b) assure that protective structures are properly designed to increase their effectiveness and reduce their impacts on Bay resources; and (c) reguire mitigation for projects that have significant adverse impacts.

Based on the information in this report, the staff recommends that the Commission take the following action:

A. Improve information provided by applicants on how proposed erosion control structures will impact Bay resources. An applicant is not currently required to provide information regarding the Bay resources affected by the proposed project. As a result, it has proven to be difficult' to analyze both the individual and cumulative impacts of erosion control projects. The information required to conduct this analysis includes: (a) photographs of the shoreline impacted by the project; (b) a description of the amount and kinds of tideland habitats that will be displaced or affected by the proposed project; (c) the project's effects on Bay resources; and (d) the long-term impacts of the proposed erosion control structure on erosion and sedimentation processes in adjoining areas. To provide this information, the Commission should direct the staff to begin the process of amending the Commission's regulations and application form.

B. A protective structure displacing 10,000 square feet or more of Bay surface area should be processed as a major permit. The Commission should direct the staff to begin the process of amending Regulation Section 10601(5) to modify the definition of protective structures qualifying as a "minor repair or improvement" to include only those projects that displace less than 10,000 square feet of Bay surface area. Projects involving more than 10,000 square feet of fill for protecting shoreline property from erosion should be processed as major permits. Projects involving less than 10,000 square feet of fill may also be processed as major permits under existing Commission Regulation Section 10621(b) if any Commissioner requests Commission consideration of an administrative application.

C. The Commission should direct the staff to initiate a cooperative, regionwide effort to create mitigation banks that can be used as appropriate mitigation for erosion control structures. Mitigation banks, supported through funds collected from applicants on a pro-rata basis toward the cost of acquiring, restoring, maintaining, and monitoring a new wetland, offer the only realistic way for applicants proposing small amounts of fill to offset the fill's impacts.

D. Improve the design of protective structures to increase their effectiveness, minimize fill, and reduce their impact on Bay resources. The design of erosion control structures should be improved as follows:

1. Erosion control structures should be designed to improve their effectiveness and minimize their impacts on Bay resources. Professionals who are knowledgeable of the Commission's concerns, such as civil engineers experienced in coastal processes, should participate in the design of erosion control structures. Designs for erosion control structures should take into account: (a) the specific erosion factors affecting the site and the criteria (such as wave height and wave period) used to determine rock size and revetment slope; (b) maintenance requirements, including costs and frequency of needed inspections; (c) the disposition of any existing protective structures on the site; and (d) possible impacts on coastal processes which would affect nearby shoreline areas through redirection of wave energy or alteration of Bay water currents, patterns of sedimentation, and erosion.

2. Engineering design plans for protective structures should be approved by the Commission. The Commission should require that engineering plans for a proposed erosion control project be

approved on behalf of the Commission to assure that: (a) the design and proposed materials are appropriate for the site and expected erosional forces; (b) the project will be constructed in accordance with sound safety standards which will afford reasonable protection to persons or property against the hazards of flood or storm waters; (c) the amount of fill proposed is the minimum necessary to protect persons and property on the shoreline; (d) the water area to be filled is the minimum necessary to protect the shoreline from erosion; (e) the location and extent of the fill is such that it will minimize harmful effects on Bay resources; and (f) the approved structure will not create erosion problems for adjoining parcels.

3. Riprap revetments should be constructed of properly sized and placed material that meets specific criteria. The Commission should require that armor stones used in revetments meet specific criteria for durability, density, and porosity, that the armor stones be properly sized and placed following sound engineering criteria, and that the revetment be free of extraneous material. Generally, only engineered quarrystone or carefully screened and sized concrete pieces

will meet these requirements. Riprap revetments constructed out of construction rubble should not , be authorized.

4. Authorized protective structures should be regularly maintained. The Commission should require that authorized protective structures include a long-term maintenance program to assure that the shoreline will be protected from tidal erosion and that the effects of the fill project on Bay resources during the life of the project will be the minimum necessary.

5. Protective structures should include provisions for marsh vegetation where feasible. Along shorelines that support marsh vegetation or where marsh establishment has a reasonable chance of success, the Commission should require that the design of authorized protective structures include provisions for establishing marsh and transitional upland vegetation as part of the protective structure.

E. All protective structures should be evaluated using the Commission's mitigation policy. Mitigation should be required for those protective structures where the Commission determines that the public benefits of the fill for erosion control does not clearly exceed the public detriment from the loss of water areas due to the fill, and where the fill will significantly and adversely affect Bay resources.

To achieve these objectives, the Commission should direct the staff to begin the process of amending the San Francisco Bay Plan to include a new section entitled "Protection of the Shoreline" with the following findings and policies:

Bay Plan Findings

a. Erosion .control projects are needed to protect important shoreline improvements. Because so much of the San Francisco Bay shoreline is urbanized, erosion control projects protect valuable and costly development from being damaged by wave action. In addition, many erosion control projects protect important public uses and services which benefit the Bay Area, or provide significant benefits to the public.

b. Most erosion control projects involve some Bay fill. Because protective structures are often built bayward of the existing shoreline, they impact Bay resources such as water surface area and volume, tidal circulation, and wetland habitat. Nonvegetated, intertidal areas (usually mudflats), which usually have high wildlife value, are the habitat most commonly affected.

c. Protective structures are both more effective and less damaging to Bay resources when they are well-designed, carefully constructed, and regularly maintained. Because factors affecting erosion vary for each site, no single protective strategy is effective in all situations. When a structure is not properly designed for a site's unique conditions, it is more likely to fail, may require further Bay fill to repair, may have higher long-term costs because of the need for more frequent repairs, and may lead to greater disturbance and displacement of the site's Bay resources.

d. Erosion control strategies that protect or enhance Bay resources (such as land use controls and marsh creation) are typically only effective in areas experiencing mild erosion. However, in some instances, it may be possible to combine marsh restoration with structural approaches to control shoreline erosion and promote Bay resources, for example, by using temporary wave stilling devices (such as floating breakwaters) or by creating areas within a protective structure that are suitable for marsh establishment. Protective structures that are more effective in protecting shoreline property in moderate to severe wave conditions generally have unavoidable adverse impacts on existing Bay resources.

e. Rubble is ineffective in halting shoreline erosion and may lead to increased fill in the Bay. Rubble, typically consisting of loose dirt, concrete or asphalt slabs of varying sizes, bricks, and other construction debris, provides some short-term protection, but typically fails rapidly in storm conditions because the rubble slides bayward or is washed offshore. To maintain protection of shoreline property, additional rubble is typically placed along the shoreline, leading to increased fill in the Bay and continual disturbance to Bay resources.

Bay Plan Policies

a. .Erosion control structures should be designed to enhance their effectiveness and minimize their impacts on Bay resources. Professionals who are knowledgeable of the Commission's concerns, such as civil engineers experienced in coastal processes, should participate in the design of erosion control structures. Designs for erosion control structures should take into account: (a) the specific erosion factors affecting the site and the criteria used to determine rock size and revetment slope; (b) maintenance requirements, including costs and frequency of needed inspections; (c) the disposition of any existing protective structures on the site; and (d) possible impacts on coastal processes which would affect nearby shoreline areas through redirection of wave energy or alteration of Bay water currents, patterns of sedimentation, and erosion.

b. Riprap i:evetments should be constructed of properly sized and placed material that meets specific criteria for durability, density, and porosity. Armor stones used in the revetment should be placed according to sound engineering criteria, and be free of extraneous material. Generally, only engineered quarrystone or carefully screened and sized concrete pieces will meet these requirements. Riprap revetments constructed out of rubble should not be authorized.

c. Authorized protective structures should be regularly maintained according to a long~term maintenance program to assure that the shoreline will be protected from tidal erosion and that the effects of the fill project on Bay resources during the' life of the project will be the minimum necessary.

d. Protective structures should include provisions for marsh vegetation where feasible. Along shorelines that support marsh vegetation or where marsh establishment has a reasonable chance of success, the Commission should require that the design of authorized protective structures include provisions for establishing marsh and transitional upland vegetation as part of the protective structure.

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TYPE OF DEVICE	TEST SITE	RELATIVE WAVE SEVERITY	COST	DESCRIPTION	PERFORMANCE
SEAWALL	No Specific Test		$400 to $1700	Seawalls are usually massive tree slanting bulkheads	Because of their large bulk seawalls are able to withstand most storm wave action, but because of their cost, they are not a viable solution in most cases.
SHEET PILE BULKHEADS					
Treated Timber	Buchroe Beach, VA	intermediate	$195	Creosote treated street pile construction	Performed well, even though backfill was washed out during big storm and had to be replaced. Some objection to bleeding creosote
Treated Timber	Telly Beach, SC	Severe			
Concrete	Folly Beach, SC	Severe	$215	Concrete slabs tied together with reinforced concrete cap.	Excellent performance. It is a clean long-lasting structure, but expensive.
Steel	No Specific Test		$210	Steel sheet piles tied together with concrete cap.	Excellent performance. May corrode over time.
POST SUPPORTED BULKHEADS					
Treated Timber	Oak Harbor, WA	Mild	$90	Horizontal planks on treated 3-inch posts lined back, filler used	Performed exceptionally well. Is long lasting and quite vandal proof
Steel and Timber	Port Wing, WI	Severe	$235	Railroad ties secured between steel H-piles. Riprap at use	Performed exceptionally well. Toe must be protected from scour.

Hogwire Fence and Sandfilled Bags	Basin Bayou, Fla	Intermediate	$40	Sandfilled bags stacked landward on the fence	Trial failed. Bags were undermined by toe scour. Bags were broken open. Posts were pushed over.
Untreated Timber (Logs)	Oak Harbor, Wash	Mild	$60	Logs attached horizontally to landward side of log posts.	Partly successful. Could be made successful with better filler and toe scour protection
Untreated Timber (Logs)	Ashland, WI	Unknown			
Tires on Treated Posts	Oak Harbor, WA	Mild	$90	Tires placed over staggered rows of treated posts and lined with gravel	Trial failed. Under wave attach, gravel washed out of tiers allowing tires to settle.
MISCELLANEOUS BULKHEADS					
Longard Tubers	Ashland, WI	Unknown	$80	69-inch tubes or 40-inch tube placed on a 69 inch at base of slope	Partly successful. Subject to vandalism and to rolling away from the slope. Could be made more efficient by moving away from slope or by providing a firm foundation.
Longard Tubers	Sanilac, MI	Intermediate			
Longard Tubers	Moran, MI	Unknown			
Longard Tubers	Empire, MI	Unknown			
Concrete Block and Timber	Folly Beach, SC	Severe	?	Vertical concrete slabs between untreated timber posts.	Failed. Concept should be rejected
Used Concrete Pipe	Beach City, TX	intermediate	?	Concrete pipes on end filled with gravel	Partly successful. Used concrete pipes must be available for actual viability. Could be made better with tie backs and a filler system

Rubble Mound	Whitefish Mich.	Unknown	$60	Pile concrete rubble parallel and a few feet from toe of slopes	Performed well. If mound is placed at the toe of the slope, it should be designed as a revetment that lies against the slope.
Rock Filled Cribbing	No Specific Test		Various	Gabion boxes placed a few feet from toe of slope.	Partly successful. Works better as a revetment.

REVETMENTS

Artificial Concrete Blocks					
Gobi (Erco)	Fontainebleau, LA	Mild	$95	15-pound blocks hand placed on filter cloth.	Partially successful. Blocks were stolen. The April 1960 storm displaced 33 square feet.
Gobi (Erco)	Holly Beach, La.	Severe			
Mats - Erco	Fontainebleau, LA	Mild	$130	These mats consisted of blocks glued onto carrier strip, placed on filler cloth	Partially successful. Mats and blocks stayed intact, but there was some slumping and displacement of slope, also some erosion at toe and shoulders of mats.
Mats - Jumbo	Fontainebleau, LA	Mild	$140		
Mats - Double Erco	Fontainebleau, LA	Mild	$160		
Turfblocks	Port Wing, WI	Mild	$160	Modules placed over nonwoven filter cloth un non-compacted fill.	Failed. Modules were displaced. Subgrade was eroded. Exposed filter cloth deteriorated.
Control Blocks	Port Wing, WI	Severe	$95	Blocks laid on nonwoven filter cloth with tongue and groove interlock.	Partially successful. Blocks in lower levels severely abraded.

Concrete Rubble	Alameda, CA	intermediate	$70	5 devices build, 4 with perched beaches	The device without the perched beach was badly damaged in 1980. In the other four, the perched beach was so effective that any type of armoring would have worked with or without filler material.
Concrete Rubble	Shoreacres, Texas	intermediate	?	Concrete rubble dumped as a riprap at the base of a low shore bluff	Although there was no filler material used, the rubble was broken into a good gradation of sizes and apparently the rubble formed its own filler blanket.
Concrete Rubble	Folly Beach, SC	Severe	?	Three devices, two were protecting bulkheads.	Devices were ineffective, badly damaged 1980
Stone Riprap	Tawas Point, MI	Severe	$80	100-pound armor stone placed on lop of filter layer at 3:1 slope.	Revetment is still performing well, preventing further shoreline recession at the site. Size of stone appeared too small for normal wave exposure.
Stone Riprap	Folly Beach, SC	Severe	$60	Five devices, each with two layers of 100 to 200-pound armor stones, over filter layer at 2:1 slope.	Revetment sustained little damage from normal wave action, however, all were destroyed by Hurricane David, Sept. 15, 1979. Size of stone appeared too small for normal wave exposure.
Stone Riprap	Port Wing, Wisc.	Severe	$145	550-pound armor stone 2-1/2 feet thick on a 2-1/2:1 slope.	Performed well without apparent damage.
Concrete Slabs	Alameda, CA	intermediate	$50	15-foot long slabs on filter cloth placed on a 60% slope.	Failed. Wave action overtopped the revetment repeatably, saturating sand slope and washing out the backfill. Revetment needs more flexibility.
Stacked Bags					
Sandfilled Bags	Alameda, CA	intermediate	$170	Bags stacked In a single row on a 60% slope. No toe protection.	Failed. Bags broke open, wave action removed embankment behind bags. 60% slope too steep, single row not enough.

Sand-Cement-Filled Bags	Alameda, CA	intermediate	$245	Same as above except lean sand cement mixture used	Partially successful. Revetment did not keep Initial shape but did provide some protection.
Sand-Cement-Filled Bags	Oak Harbor, Wash	Mild	$90	Bags of sand-cement mix stacked in double row with filter cloth or material and low protection and drain pipes.	Performed well. Success attributed to flatter slope, two-bag thickness, use of weep holes and toe protection, wet mixed burlap bags tried instead of dry mixed paper bags which worked as well.
Gabions	Oak Harbor, Wash	Mild	$70	1-foot, 6-inch thick mattresses placed side by side on 1-1/2: 1 slope with toe protection but no filler layer.	Partially successful. Backfill lost from behind top edge of control slope. Gabions were reconstructed using filters. Both filter layers and filter cloth worked effectively.
Fabric	Alameda, CA	intermediate	$60	A Fabriform nylon mat over Mirafi-140 filler cloth was filled with sand.	Failed. Subject to vandalism and deterioration of the fabric.
Fabric	Fontainebleau, LA	Mild	$85	Pocket filler cloth ballasted with shells.	Failed. Wave action destroyed fabric.
Tire and Fabric	Fontainebleau, LA	Mild	$100	Sand-cement bags and cloth used to make a Dutch toe. Tires placed on cloth and filled with dry-sand-cement mixture.	Failed. When waves became 3 feet or higher the tires became buoyant.
Steel Fuel Barrels	Kotzebue, AK	Severe	?	Two double rows of barrels, to feet apart with barrel diaphragms between.	Partially successful. Performed quite well during a short monitoring period, but corrosion would prevent this from beinga viable solution.

BREAKWATERS AND SILLS

Tires on Piles	Fontainebleau, LA	Mild	$120	Tires banded together, placed on and fastened to timber piles.	Performed well.
Sand-Cement-Filled Bags	Alameda, CA	intermediate	$30	Sand-cement mixture poured into nylon bags. Bags supported by wooden forms.	Performed well. Despite subsidence of parts of the breakwater, it continued to function as a sill.
Sand-Cement-Filled Bags	Fontainebleau, LA	Mild	$56	Sand-cement filled bags stacked in a trapezoidal section 4 feet high and wrapped in filler cloth.	Performed well.
Timber Sheet Piles	Slaughter Beach, DE	intermediate	$130	2-inch by 12-inch by 10-foot long sheet piles	Performed well.
Stone Rubble	Siuslaw River, OR	Mild	$190	Full height breakwater with groin stone core and 3 feet of armor stone on tip and on water side.	Performed well.
Stone Rubble	Kitts Hummock, DE	intermediate	$275	550-pound to 1200-pound rock dropped onto existing rock for low sill with 5-food top width.	Performed well.
Floating Tire	Stuart and Jenson, FL	Mild	$85	Tires bolted together and anchored in place	Partially successful. Problems with anchor and fasteners and with floatation material.
Floating Tire	Pickering Beach, DE	intermediate	$1,400	Tires bolted together and anchored in place	Partially successful. Problems with anchor and fasteners.
Longard Tubes	Alameda, CA	intermediate	$330	69-inch Longard tube on a strip of filter cloth with 10-inch hold-down tubes on each side.	Partially successful. The breakwater successfully resisted damaged by natural forces but was continually being damaged by vandals. March 1979 storm washed out a previously vandalized section.

Longard Tubes	Basin Bayou, FL	intermediate	$155	69-inch Longard tube on a strip of filter cloth with 10-inch hold-down tubes on each side.	Partially successful. Breakwater worked successfully until destroyed by vandals.
Gabions		Severe	$455	Baskets filled with stones 3 to 9-inches, with toe protection.	Partially successful. Good performance initially, but structural failure seemed imminent.
Z-Wall	Geneva Park, OH	Severe	$265	Steel -reinforced concrete panels set on edge in zigzag fashion and fastened together with large hinge bolts.	Partially successful. Good performance until structure deteriorated. Hinge system needs improvement.
Surgebreaker	Basin Bayou, FL	intermediate	$160	Constructed with 5700-pound precast concrete triangular modules placed end to end on bay bottom.	Partially successful. Performed well and remained structurally sound but was not tested for a long enough period to determine if it is a long-term solution.
Sandgrabber	Basin Bayou, FL	intermediate	$155	Hollow concrete blocks, similar to, but larger than building blocks placed by hand with hollows facing seaward and tied together with U-shaped steel rods.	Partially successful. Has locally effective but depleted downdrift beaches. Some structure deterioration.
Sandgrabber	Folly Beach, SC	Severe	$155	Same as "Basin Bayou"	Same as "Basin Bayou"
Concrete Boxes	Kitts Hummock, DE	intermediate	$155	5 by 7 by 4-feet concrete boxes placed on bottom in a row with open end up, with toe protection	Partially successful. Fair performance but should have covers to keep sandflll in boxes.
Concrete Boxes	Slaughter Beach, DE	intermediate	$110	54 by 74 by 2 feel concrete boxes placed on	Partially successful. Fair performance but should have covers to keep sandfill in boxes.

				bottom in a row with open end up.	
Sandfilled Bags	Kitts Hummock, DE	intermediate	$135	Nylon bags filled with sand.	Failed. Poor performance. Bags failed and sand was lost.
Sia-pods	Geneva Park, OH	Severe	$150	Special concrete units with four inclined legs attached to a cylindrical trunk.	Failed. Poor performance. Structure undamaged but did not attenuate waves.
Brush Dike	Fontainebleau, LA	Mild	$40	Brush placed between two rows of posts on 4-foot centers.	Failed. Performed well until April 1980 storm when most of the brush was washed away.

GROINS

Timber	Ninilchik, AK	Severe	$115	5-inch by 12-Inch Spruce planks on 12-fool Spruce piling on 5-foot center s.	Excellent performance.
Timber	Lincoln Township	Unknown	$65	Timber on piling	Excellent performance.
Timber and Rock	Sanilac, MI	intermediate	$40	Rock filled timber crib.	Excellent performance.
Timber and Rock	Folly Beach, SC	Severe	$235	Sheet piling with rock toe.	Excellent performance.
Stone Rubble	Siuslaw River, OR	Mild	$85	500 pound to 3000-pound groin slope, 16-foot top.	Excellent performance.
Concrete Rubble	Broadkill Beach, DE	Severe	$70	Broken concrete.	Excellent performance but may not be stable with high waves.
Sand-Cement-Filled Bags	Alameda, CA	intermediate	$45	Nylon bags filled with sand-cement mixture.	Excellent performance but may not be stable with high waves.
Corrugated Metal Pipe	Ninilchik, AK	Severe	$450	10-foot lengths of 4-foot dia pipe buried endwise in ground with cap.	Excellent performance

Rock Mastic	Sanilac, MI	intermediate	$200	Hot asphalt mastic poured over rock groin.	Good performance despite loss of groin end.
Longard Tubes	Ashland, WI	Unknown	$110	69-inch tube on a strip of filter cloth with 10-inch holdown tubes on each side.	Partially successful. Performed well until damaged by debris or vandalism.
Longard Tubes	Sanilac, MI	intermediate	$70	two-40-inch tubes.	Partially successful. Performed well until damaged by debris or vandalism.
Longard Tubes	Sanilac, MI	intermediate	$90	one-69-inch tubes.	Partially successful. Performed well until damage by vandalism caused sand to spill out.
Gabions	Sanilac, MI	intermediate	$40		Partially successful. Performed quite well even though there was some settlement and boxes on end of groin was exposed.
Sandfilled Bags	Sanilac, MI	intermediate	$140	9 by 3 by 2- foot bags.	Failed. Bags were damaged and sand escaped
NON STRUCTURAL SYSTEMS					
Perched Beach	Alameda, CA	intermediate	$50	Perched beach enclosed by low Sand Pillow sill and sized rubble revetment with filler cloth.	System very effective. Could be used at small sites.
Beach Fill	Alameda, CA	intermediate	$50	Sand dumped on beach and retained by a groin.	Excellent Performance. After initial fill no additional sand was required.
Vegetation Only	Alameda, CA	intermediate	$8	Pacific cordgrass planted in unprotected areas. Intertidal.	Failed. Less than 10 percent survived first growing season.

Vegetation Only	Fontainebleau, LA	Mild	$15	Smooth cordgrass planted unprotected intertidal areas.	Limited success. Most of the plants were washed out as a result of wave action and the inland movement of sand caused by the high waves.
Vegetation Only	Basin Bayou, Fla	intermediate	$17	Smooth cordgrass and saltmeadow cordgrass were planted in unprotected beach areas.	Survival of both species was very poor.
Vegetation with Structure	Basin Bayou, FL	intermediate	$17	Smooth cordgrass and saltmeadow cordgrass wore planted in protected areas behind a sandgrabber	Partially successful. Plants had a 90 percent survival rate the first growing season but was almost entirely wiped out by moving sand the next year.
Vegetation with Structure	Alameda, CA	intermediate	$8	Pacific cordgrass planted in area protected by breakwater, intertidal.	Partially successful. Plants in area suffered a 66 percent loss in first season and a 30 percent loss of the remainder the second season. Area 3 lost 15 percent the first season and 40 percent the second.
Vegetation with Structure	Oak Harbor, Wash	Mild	$4	Area planted was narrow strip of upland between revetments and bluff.	Partially successful. Vegetation well established during first season but was 90 percent destroyed by storms of December 1970 and February 1979.