"Design with Nature" Strategies for Shore Protection: The Construction of a Cobble Berm and Artificial Dune in an Oregon State Park

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Introduction

The book "Design with Nature" was written by the Scotsman Ian McHarg, a town planner and landscape architect. With the advances in the science of ecology during the 1960s, the focus of his book (published in 1969) concerned what constitutes a natural, sustainable environment, with one chapter having been devoted to the preservation of barrier islands. On the basis of our investigations of the designs of environmentally compatible shore-protection structures as substitutes for conventional armor-stone revetments or seawalls, we have expanded on McHarg's concept to include the idea that we can learn from nature in the search for improved ways to protect our shores from the extremes of waves and tides (Komar, 2007). Our goal is to design structures that are more natural in appearance, while at the same time providing an acceptable degree of protection to coastal properties.

Figure 1. Natural cobble beach on the shore of Oceanside, Oregon, which has protected the sea cliff from erosion, evident in its extensive cover of vegetation.

Our interest in this philosophy was initiated by the erosion experienced in a state park on the Oregon coast, where a high protective dune ridge had been eroded away, followed by a major storm in 1999 that washed through the campground destroying much of its infrastructure (Allan and Komar, 2002; 2004). It was apparent that some form of shore protection was needed, but it was decided that a conventional riprap revetment or seawall would be incompatible with this natural park setting. Instead, the decision was to construct a cobble berm that is effectively the same in appearance and in its dynamics to a natural cobble beach, backed by an artificial dune that is reinforced by a core of sand-filled geotextile bags. This decision to construct a cobble berm to protect the park was based on observations along the Oregon coast that the presence of a natural cobble beach can provide a significant degree of protection to ocean-front properties. Figure 1 shows an example of such a beach on the shore of the community of Oceanside, where the absence of erosion is evident in the heavy vegetation that covers the sea cliff, with photos dating back to the early 20th century being essentially identical.

The choice of a cobble berm backed by an artificial dune for shore-protection in the eroding state park proved to be cost effective, the expense being a small fraction of what it would have cost to construct a revetment or seawall. Important for the park visitors, the completed cobble berm and artificial dune are nearly indistinguishable from their natural counterparts on the Oregon coast, such that the visitors have little or no notion that these are in fact shore protection structures.

Here we report on the successes and limitations of these "Design with Nature" structures, their installation in this state park having been something of a "test case" on a prototype scale in applying environmentally compatible structures for shore protection. This paper ends with a broad discussion of this philosophy with suggested variations on its potential approaches directed toward protecting coastal properties.

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Cobble Berms and Artificial Dunes

The idea for constructing a cobble berm for shore protection can be traced back to the early 1970s, when an artificial gravel beach was constructed along the bank of the entrance to Rotterdam Harbor in the Netherlands, primarily to dissipate the energy of ship wakes. This approach came to be referred to by engineers as a "dynamic revetment," in the sense of it being composed of gravel and cobbles that can be readily moved by waves, in contrast to being static, as in a conventional riprap revetment built of large quarry stones (Ahrens, 1990). An alternate name used by coastal scientists is "cobble berm," a term that may be more acceptable in management applications, where the use of engineered revetments or seawalls are discouraged, or outright forbidden by law.

There are a number of advantages in using a cobble berm for shore protection rather than a rock revetment or seawall. Stone sizes are significantly smaller than required for armor in a riprap revetment, and construction is simpler than that of a conventional revetment, in which each massive stone must be individually placed in order for the structure to be stable. Although more material generally is needed for a cobble berm, the gravel and cobble-sized material is less expensive and more readily available than armor stone, either being "pit run" material from a quarry, or gravel and cobbles derived from natural sources (for example, rivers or other beaches).

Another advantage is that because a primary goal in constructing a cobble berm is that it has the general appearance and morphologic details of a natural cobble beach, to a degree this makes its design and construction relatively straightforward. The design first involves an assessment of the volume of gravel and cobbles that will be required to produce a berm having a sufficient width and elevations so that it will provide a buffer for shore-front properties from the expected combinations of extreme tides and storm waves. Placement of the cobbles in the berm during construction mainly involves the creation of a beach that has the expected equilibrium slope for its grain sizes and the wave climate of the site. This choice of a slope in the design need only be a first approximation in that it can be expected the cobbles will be transported and sorted by the waves into what constitutes the correct "design" for that site.

It is fortunate that conceptually the design of a cobble berm/dynamic revetment is relatively simple in that only limited research has been undertaken by coastal engineers directed toward their design, with their studies having mainly involved experiments in laboratory wave channels. More relevant have been the field investigations over the years of gravel and cobble beaches undertaken by geologists, which have documented their slopes, morphologic responses to storms (their morphodynamics), and the rates of transport and size sorting of the cobbles. When faced with the design of a cobble berm, those past studies provide guidance, but it is also important to investigate the natural cobble beaches along the coast where the artificial berm is to be constructed. This was the objective of the study by Everts and others (2002) of the cobble beaches on the coast of southern California, in preparation for the construction of a test-section cobble berm in Ventura. Similarly, in preparation for the design and construction of the cobble berm to protect the eroding state park on the Oregon coast, as illustrated in figure 2, we initiated an extensive study of the natural cobble beaches, including those within the park itself (Allan and Komar, 2004).

Figure 2. Natural cobble beach on the Oregon coast, being surveyed and with the cobble sizes measured to serve in the design of the artificial cobble berm for shore protection in Cape Lookout State Park.

Conceptually, the construction of a cobble berm is not much different from the implementation of a beach nourishment project, both being “soft” approaches to beach restoration and shore protection. Although both involve the importation of sediments, beach nourishment most commonly is directed toward the restoration of an existing beach composed of sand, although there have been cases of the nourishment of gravel beaches. The primary objective in constructing a cobble berm is not beach restoration and could equally be undertaken on a shore where there had not been a pre-existing cobble beach. As has been the case for the state park on the Oregon coast, the choice of constructing a cobble berm primarily could represent an alternative to a “hard” structure, a riprap revetment. Furthermore, there are aspects in the design and construction of a cobble berm that differ from those in beach nourishment. In the end, however, the distinction is subtle and not particularly important as both involve “soft” solutions, and both are variations on the “Design with Nature” philosophy.

Nourishment of sand beaches along the United States East and Gulf coasts generally has the objective of restoring recreational beaches, although it is recognized that in having created a wider beach it also serves to protect the shore-front properties by dissipating the energy of the waves. However, it is fairly standard practice to include the restoration or construction of foredunes at the back of the nourished beach; this mainly having the objective to protect the properties from the combined surge and waves of storms. At some sites, the restored foredunes have been reinforced with a core of sand-filled geotextile bags or a long geotextile tube. For example, this approach was used to protect homes on Galveston Island, Texas, a low-lying barrier island that has experienced decades of shoreline recession and impacts from storms, with minimal development of a natural foredune that offered protection to the homes (Heilman and McLellan, 2003). Although the waves of even modest tropical storms were able to wash away the sand of the small constructed dunes, the geotextile tubes generally remained in place, offering for number of years a degree of protection to the homes. However, that protection proved to be insufficient during Hurricane Ida in 2008, when its surge and waves washed over the entire barrier island destroying nearly all of the homes.

The Erosion of Cape Lookout State Park

Although the construction of a cobble berm for the protection of coastal properties had not been previously demonstrated on a prototype scale to be a satisfactory management strategy, the substantial evidence offered by the natural cobble beaches along the Oregon coast recommended this approach when erosion significantly damaged the facilities at Cape Lookout State Park on the northern Oregon coast (Allan and Komar, 2002 and 2004; Komar, 2007). The added protection offered by the restoration of the foredunes suggested their inclusion in the impacted area.

Cape Lookout State Park lies at the south end of Netarts Spit, north of the Cape Lookout headland (fig. 3). Prior to its erosion, a wide sandy beach had existed along this shore, backed by a ridge of high dunes covered with thick vegetation, including large trees. The presence of those dunes sheltered an extensive campground, one of the most popular on the Oregon coast. The inception of the erosion occurred during the major El Niño of 1982–83, which produced erosion at a number of sites along the coast (Komar, 1986). A significant factor was that during a major El Niño the measured tides throughout the winter are on the order of 0.5 m above the predicted astronomical values, resulting from the combined effects of the ocean water along the coast being warmer than usual, the higher temperatures producing a thermal expansion of the water, and with the geostrophic effects of intensified northward flowing ocean currents acting to pile water up along the shore. The result of the elevated water levels is that during a major El Niño many of Oregon’s low-sloping beaches are “flooded out” at all stages of the tides, so that the storm-generated waves are able to reach and impact the sea cliffs and foredunes, resulting in significant erosion of shore-front properties.

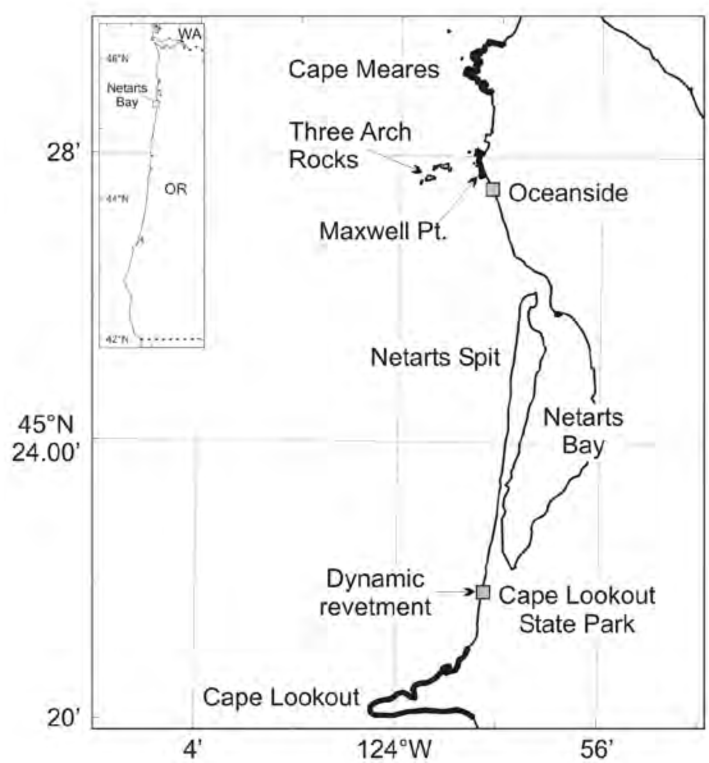

Figure 3. Netarts Littoral Cell on the northern Oregon coast, the location of Cape Lookout State Park where a cobble berm and artificial sand dune were constructed for shore protection.

Figure 4. Erosion of Cape Lookout State Park, photographed during the 1997–98 El Niño. The remnants of the high dune ridge and a failed log seawall are seen in the background. Riprap temporarily protected the bathrooms, but they were removed after having been damaged the following winter when the March 1999 storm breached this area and washed through the campground (Allan and Komar, 2004).

The elevated monthly-mean water levels and tides were an important factor in the erosion of Cape Lookout State Park, but most significant was that the park is positioned in what we call a zone of "hot-spot" erosion, where the greatest impacts have occurred during major El Niños. During the winter of an El Niño, the storms crossing the Pacific Ocean tend to follow more southerly tracks than during normal winters, so they cross the coast of central California rather than the shores of Oregon and Washington. As a result, the sand on Oregon's beaches is transported alongshore to the north by the waves that arrive from the south-southwest, creating hot-spot zones of erosion immediately north of headlands, where the greatest losses of beach sand are experienced, leading to the complete loss of the protective beach at some sites. The unprecedented erosion at Cape Lookout State Park during the 1982-83 El Niño therefore largely was a result of a classic example of concentrated hot-spot erosion caused by its position just north of Cape Lookout (fig. 3).

To a large extent, the Park's beach recovered following the 1982–83 El Niño, as the sand returned from where it had been temporarily displaced to the north. There was little additional loss of Park grounds until the next major El Niño in 1997–98, when there was a near repeat of the processes and impacts, leading to the loss of more of the high protective dunes (fig. 4). In a "one, two punch," the following winter of 1998–99 was eventful in that there were a series of exceptional storms, with the strongest in early March 1999, which generated 14-m wave heights that combined with high tides to flood across the Park's campground, which was no longer protected by a ridge of dunes (Allan and Komar, 2004).

After the Park experienced significant losses to erosion and flooding, the choices seemed to be either to abandon the campground or to construct a conventional rock revetment that would consist of sufficiently massive quarry stones to withstand the high wave energies of the Oregon coast. Such a structure would have required that it be designed by an experienced coastal engineer, and its construction would have had to be undertaken by a private contractor using heavy-duty equipment to individually place the stones. The estimate of the cost for constructing a riprap revetment having the required vertical scale and length of 300 m was placed at $500,000; in reality the cost likely would have been much higher because stone would have to be trucked in from the Columbia Gorge because of the lack of suitable stone size in the quarries along the coast.

In addition to the concerns regarding the cost involved in its construction, there was an inherent aversion on the part of State Park's officials to having a "hard" structure in the Park, a high mound of rocks between the campground and the recreational beach. Such concerns ultimately led to the decision to construct the cobble berm backed by a line of restored sand dunes, which was viewed as being an environmentally compatible approach in this park setting. A cobble beach was already present along much of the length of Netarts Spit, backing the otherwise dominant sand beach. However, in the area of the developed park, the deposit of cobbles was too low in elevations and width to provide adequate protection; we had not even been aware of its existence prior to its being uncovered by the erosion of the sand beach and loss of the high dunes. Although inadequate, this narrow cobble beach along the eroding shore supported the decision to import additional gravel and cobbles to construct a cobble berm. A decision also was made to include the construction of a restored foredune that would back the cobble berm, a line of low dunes that would replace the high dune ridge that had been lost. In recognition of the reduced scale of the artificial dunes, it was decided to reinforce them with a core of sand-filled geotextile bags.

Design, Construction, and Monitoring

The design for the cobble berm and restored foredune is shown in figure 5, consisting of two “Design with Nature” components, having become a “hybrid” structure (Komar, 2007). The coupling of these two components was such that each could be downsized compared with its scale required if constructed alone. If only the cobble berm had been constructed, for the berm to adequately protect the park it would have had to be much larger and reached a higher elevation at its crest, to prevent overtopping during storms. That would have represented a problem given the limited availability of gravel and cobbles for construction. The decision to include the restored foredunes made it possible to reduce the size of the cobble berm, since the presence of the dunes would block the extreme water levels of tides and waves during storms that would overtop the berm and potentially carry cobbles as projectiles into the campground. At the same time, although downsized, the cobble berm would dissipate much of the wave energy so the dunes would not have to be as massive and as high in elevation to prevent overtopping. The elevations of the components of the structures given in figure 5 (relative to the NAVD 88 datum) were based on calculations of the total water levels expected during extreme tides and storm-generated waves, confirmed by surveys of the elevations of the natural cobble beaches and their landward vegetations lines, and evidence for the total water level reached during the extreme March 1999 storm that had flooded the Park’s campground.

The artificial foredune was constructed first, its core consisting of 2,750 geotextile bags, each filled with approximately 0.7 m^3 of sand. The sand for the reconstructed dunes came from an area several kilometers to the south of the park, where there had been problems with sand blowing onto the roadway. The mound of bags was buried beneath 15 to 30 cm of sand, covered with a biodegradable jute-coconut fiber mat (fig. 6), that in turn was covered by another layer of loose sand planted with dune grass that is native to the Oregon coast (*Elymus mollis*). The construction of the cobble berm was undertaken following the completion of the dune. The cobbles were obtained from natural accumulations on the beaches within the Park, primarily toward the north end of Netarts Spit, where the net northward transport of the gravel and cobbles tends to accumulate, and where erosion of the dunes has been minimal and infrastructure is not present. The cobbles were transported to the construction site on a front loader (fig. 6) and placed evenly across the pre-existing profile of the natural cobble beach. The top of the added cobble berm overlaid the scour blanket that had been placed beneath the artificial dune, and lapped up onto the front of the constructed dunes to offer protection from the waves. No attempt was made to provide toe protection for the placed cobbles as would normally be done in the construction of a conventional static revetment. The deposit of cobbles instead extended below the beach sand in the offshore, providing the primary toe support for the constructed cobble berm.

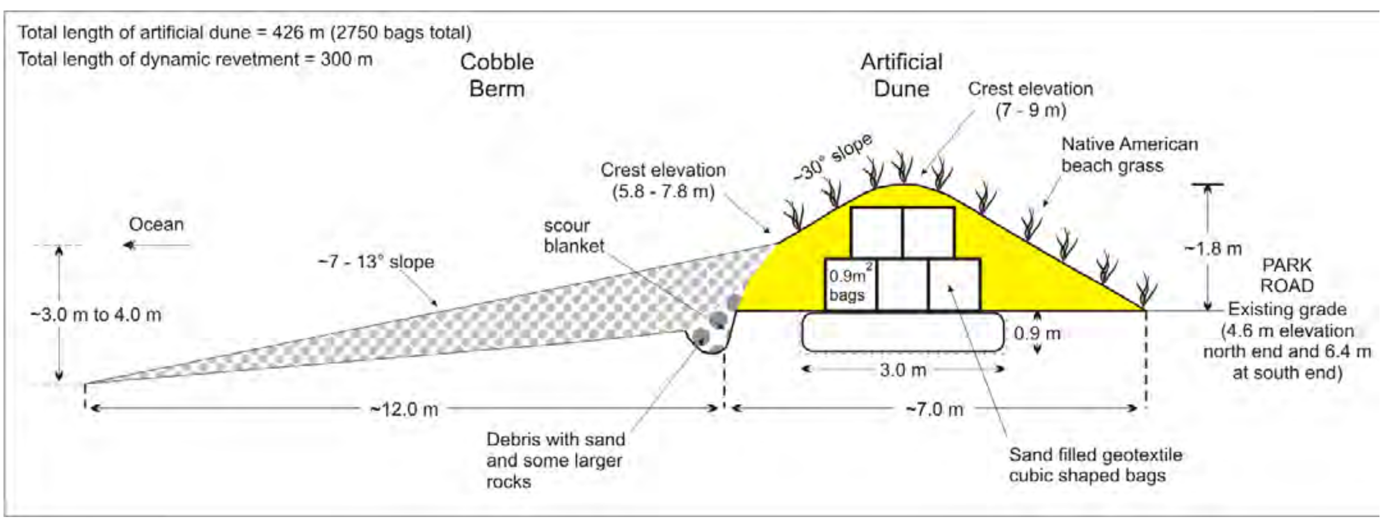

Figure 5. Design for the cobble berm and reinforced foredune to protect Cape Lookout State Park from erosion and flooding. The elevations are referenced to the NAVD 88 datum.

Figure 6. Construction of the cobble berm and artificial foredune in Cape Lookout State Park during the fall of 2000. A continuation of the old dune ridge is seen in the background, which had previously extended past this area of erosion.

Construction of the 300-m long cobble berm and artificial foredune was completed by December 2000, prior to subsequent major storm events. Growth of the planted vegetation quickly covered the dune so that, as seen in figure 7, the completed project had the desired appearance of a natural cobble beach and foredune as seen along the Oregon coast. Their construction was undertaken by Oregon State Parks and Recreation Department, with the employment of work-released labor from the State penitentiary. This kept the total cost of the project to approximately $125,000, significantly less than the $500,000 estimated cost for a conventional static riprap revetment having the same 300-m length.

The construction of these environmentally compatible structures for shore protection provided the opportunity to monitor them, to determine their degrees of success, and possibly to improve their designs for future applications (Allan and Komar, 2004). Monitoring included a program of periodic surveys and analyses of the tides and wave runup that occurred during the winter storms for comparison with the structure elevations and surveys of the morphologic responses to extreme storms. The surveys immediately demonstrated that the constructed cobble berm and foredune did not meet the design specifications in terms of their elevations required to limit overtopping by the expected wave runup elevations of major storms. The top of the dune along the northern one-third of the structure was found to be 1 to 2 m below the 8 to 9 m NAVD 88 recommended elevation, although the southern one-half meet the specifications. As seen the photograph in figure 7, taken soon after a winter storm, the cobble berm experienced frequent attack by even modest storm waves, although the line of restored foredunes provided a variable level of defense, overtopping occurred along its northerly stretch of lowest elevation. On at least one occasion during our monitoring program, extreme waves were documented to have overtopped the entire length of the structure.

This significant construction “flaw,” however, resulted in a more meaningful “experimental test” of the structure’s capacity to withstand the forces of extreme waves and tides. Although wave overtopping has occurred a number of times since construction was completed in 2000, occasionally carrying a few cobbles and drift logs into the campground, both the cobble berm and foredunes largely have remained intact. The combination of the cobble berm backed by a line of foredunes has proven to be an effective strategy in protecting Cape Lookout State Park from storms that otherwise would have rendered the campground unusable (Allan and Komar, 2004).

Being a “soft structure” with the waves able to entrain and transport the cobbles on the constructed berm, it was expected that some replenishment eventually would be required. Our monitoring surveys extended alongshore beyond the length of the constructed cobble berm, demonstrating the occurrence of continued erosion along the adjacent

Figure 7. Completed cobble berm and foredune, having been overtopped by a winter storm along the stretch that had not been constructed to the designed elevations. The riprap that previously had protected the bathrooms (fig. 4) can be seen in the background.

unprotected stretches of the park. That erosion has been particularly severe to the immediate south of the structures, and began to impact the volumes of cobbles within the constructed berm. As part of our monitoring program we traced the movement of a large number of cobbles with PIT (passive integrated transponder) tags, to document their mobility and net transport within the cobble berm (Allan and others, 2006). It was found that the cobbles are transported alongshore toward the north, carried in that direction by the waves of winter storms that arrive from the southwest. With the eroding beach to the south being deficient in gravel and cobbles, it has been unable to supply beach material to replace that being lost from the cobble berm. The result was that by 2008 the cobble berm had lost 5,000 m^3 of gravel and it was evident that maintenance was required. During that summer, State Parks added about 3,500 m^3 of gravel and cobbles to the berm, most of it recovered from where the lost material had accumulated near the north end of Netarts Spit. The maintenance during the summer of 2008 still left the cobble berm deficient in cobbles, about 1,500 m^3 less than when it was constructed, so its capacity to protect the park from winter storms remains compromised.

With the almost annual wave overtopping of the foredunes where they had not been constructed to the design elevations, it has become evident that in places the vegetation and sand cover has been lost, exposing the geotextile bags. A decade after their construction, maintenance is definitely needed, and it also has been recommended that in the process their elevations be raised to bring them closer to those specified in the original design. Along the southerly stretch of constructed foredunes, which had achieved the design elevation, there has been minimal degradation of the dune as a result of the absence of frequent overtopping; this stretch of constructed foredune demonstrated its capacity to protect shore-front properties if properly designed and constructed.

In spite of not having been constructed to their designed elevations along their entire length and not having been adequately maintained, the cobble berm and foredune in Cape Lookout State Park have survived the intensity of wave attack on the high-energy Oregon coast, and have provided an acceptable level of protection to the campground. Furthermore, it is evident that had they been constructed to the elevations needed to prevent overwash, and with a longer length or having included a feeder beach of cobbles to the south, their stability would have been significantly greater. But from this experience it was reaffirmed that being “natural,” such structures are dynamic and require some level of periodic maintenance. However, even including the expenses for maintenance they can be expected to cost far less than a conventional rock revetment or a seawall (bulkhead), and most importantly, they provide a natural form of shore protection from erosion and flooding, one that is compatible with their coastal setting.

“Design with Nature”—Variations on a Theme

There potentially are variations on this “Design with Nature” approach for shore protection, involving other components and designs than were employed in Cape Lookout State Park. For example, rather than constructing an artificial dune as backup for the cobble berm, a scaled down boulder revetment could be used. The incorporation of a seemingly static revetment might seem contrary to this philosophy, but large-stone “revetments” can be found in nature wherever coarse material is available along the shore. For example, such accumulations are found along the rocky coast north of San Francisco, providing toe protection to the large active landslides that are common along that coast. Our recognition of this natural development of self-protection by landslides proved to be of interest when the California State Highway Department decided to dispose of rocks and sediment derived from the reconstruction of a stretch of highway by dumping the excavated material from the mountainside down the steep cliff face, in effect creating a massive artificial landslide. This provided another “experiment” that permitted the documentation of the early stages of landslide erosion, mainly involving the processes of waves cutting away the toe of the slide (Komar, 1997 and 1998). The material being disposed of in that slide came from the Franciscan Formation, which contains a full range of sediment sizes from clay to large boulders. It was observed that a beach immediately began to form along the toe of the eroding slide, consisting of the coarsest materials, gravel, cobbles and boulders. With its accumulation, the rate of toe erosion progressively slowed, the material having sorted itself into a protective gravel and cobble beach, backed in riprap-like fashion by a line of armor-sized boulders.

The natural landslides and the evolution of that artificial slide on the California coast illustrated the potential for another “Design with Nature” strategy for shore protection. They also demonstrated the basic difference between the regularity of a riprap revetment designed by an engineer, compared with nature’s design where there is far less organization in the piling of the boulders, and their presence tends to blend to a greater degree with the fronting cobble beach. The design of such a hybrid cobble berm plus a boulder revetment is illustrated in figure 8, having been proposed to protect an eroding mudstone bluff on the coast of New Zealand, where a cobble beach was already present but was insufficient to protect the bluff and homes. Previously, unnatural gabions had been used to protect the bluff from the attack by waves, each gabion consisting of a wire-mesh cube filled with cobbles; however, within a few years the wire mesh rusted, and most of the gabions were broken apart by the waves. It is apparent in figure 8 that the replacement of the gabions with boulders and the addition of cobbles to the beach represented a far more aesthetic and effective

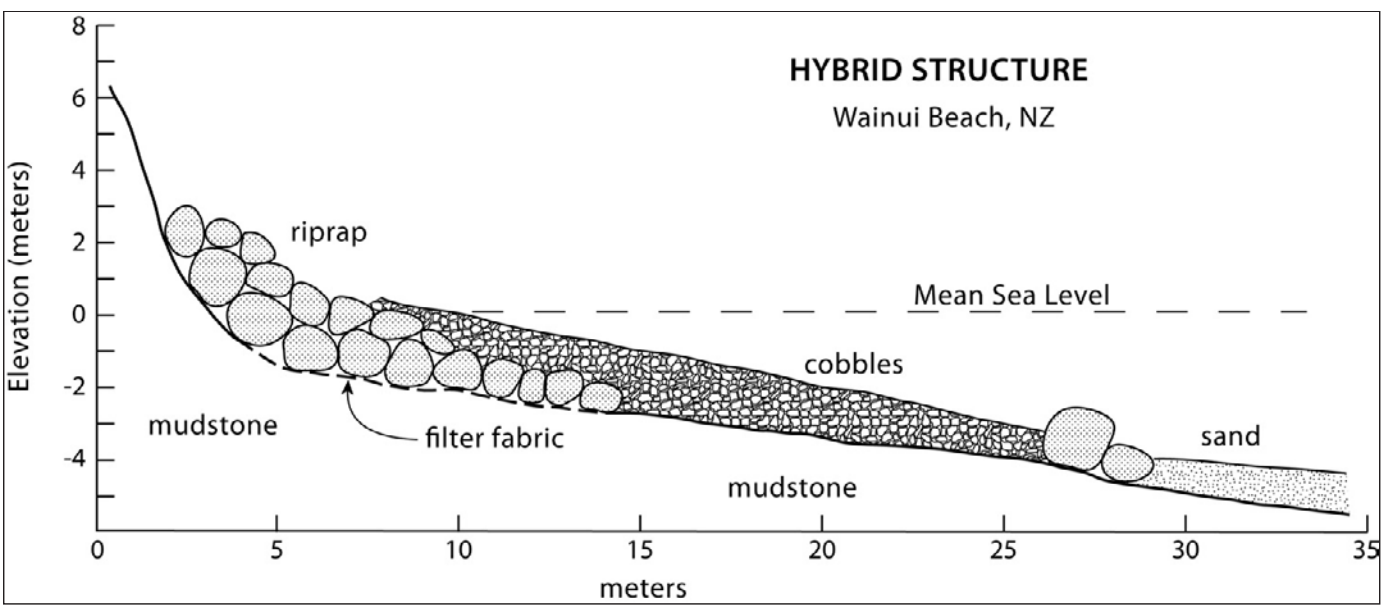

Figure 8. Hybrid “Design with Nature” approach for protecting a bluff from erosion, consisting of a cobble berm backed by a natural form of boulder revetment.

Figure 9. Logs at the back of a gravel beach on the shore of Puget Sound, placed to protect the property from high tides and waves.

structure. Similar to the combination of the cobble berm and artificial foredune constructed on the Oregon coast, this combination permitted the use of a scaled down line of boulders since the cobble beach would first act to dissipate the energy of the waves. Alongshore from that site, which lies at the end of a pocket beach within a bay, the cliff is fronted by a sand beach rather than cobbles, and wind-blown sand tends to accumulate during the summer to form a foredune, which, however, is frequently eroded during winter storms, leading to erosion of the bluff. It was proposed to use a constructed foredune reinforced with geotextile bags, virtually like that in Cape Lookout State Park. Although it is expected that much of the sand in the dune would be lost during winter storms, the presence of the geotextile bags can be expected to continue to protect the bluff and homes from wave attack, until the dune is naturally reformed by the wind the following summer, or is artificially restored by “beach scraping” (bulldozing a portion of the summer beach onto the dune).

A variation on that seen in figure 8, but on a smaller scale, was constructed along the shore of Yaquina Bay on the Oregon coast, where erosion was impacting a pathway leading from the Mark Hatfield Marine Science Center of Oregon State University, used by visitors to view this natural estuarine environment. It again was deemed undesirable to construct an imposing “hard structure”, and based on our recent experience at Cape Lookout State Park, it was decided again to construct a gravel-cobble berm. But in this application the design included a line of large rocks in the water along the toe of the fill, upgraded from those illustrated in figure 8 to have a sufficient size such that they would not be displaced by wind-generated waves on the bay or by ship wakes. This simple approach has been successful in protecting the shore and path from further erosion, while being entirely natural and compatible with in this estuarine setting.

Another potential design component is the use of drift logs, which are common on most shores in the Pacific Northwest. On the Oregon coast, logs accumulate locally in large numbers at the back of the beaches, their crisscrossing arrangement providing a degree of self stability even when impacted by high tides and waves, being important to the entrapment of wind-blown sand and the growth of foredunes. Similar to the use of the boulder revetment in figure 8, a “Design with Nature” protection consisting of a line of logs could be employed as backup for a constructed cobble berm or natural gravel beach, but this would need to be designed to be stable and protective of the shore, while at the same time maintaining as natural an appearance as possible, not making it look too much like a designed wall.

An example of the use of logs for shore protection in Puget Sound, Washington, illustrated in figure 9, consists of a largely random arrangement of logs, held by anchored chains, that have been placed at the back and out across the beach. This example demonstrates the potential use of drift logs on low-fetch shores where drift wood is plentiful and the wave energy is relatively low. Interest in this approach likely also stems from it being a low-coast approach to protecting one’s property. However, the designs are questionable and there has been little or no monitoring to document their stability and effectiveness. Because most beaches in Puget Sound being composed of gravel and cobbles (fig. 9), a common strategy for shore protection involves beach nourishment or the construction of a cobble berm (Shipman, 2001), that expands the potential for employing a variety of “Design with Nature” approaches for shore protection in Puget Sound, with a reasonable expectation that the property will be defended for a number of years. The applications in Puget Sound, and along other coasts, only require a greater level of imagination and creativity rather than constructing still another massive rock revetment or seawall.

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