SAFE HARBOR
ENVIRONMENTAL MANAGEMENT
HABITAT RESTORATION

Stabilizing Slopes, Very Steep Slopes & Coastal Banks

Above: Two images of steep coastal bank in Brewster, taken 1 year apart.

Safe Harbor recommends natural system alternatives for more sustainable stabilization of steep, very steep slopes and coastal banks. Natural system geomass and biomass respond to system energy with compatible linkage to scale.

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Sustainable, natural system solutions for slope stabilization should always be considered. We believe the key to solving many environmental problems can be found within the problem itself. Our sustainable solution to steep slope erosion uses gravity to control runoff and native vegetation to control erosion. Bioengineered mitigations and infiltration systems perform stabilization functions, gradually self-incorporating into sustainable, leaf-stem-root systems. Safe Harbor has developed innovative, low-impact access and implementation techniques, which are described in this booklet. These tools can be utilized to create stabilized natural systems that sustainably infiltrate storm water, minimize erosion and perform at zero discharge.

We also discuss techniques and strategies for stabilizing eroded Ocean Bluffs and Bayside Bluffs, using systems that work with coastal processes.

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A word about Safe Harbor: *We provide environmental permitting and management services for Coastal Construction, Invasive Vegetation and Coastal Resource Restoration projects under the jurisdiction of the Massachusetts Wetlands Protection Act; Massachusetts Endangered Species Act; Local Wetlands Bylaws and ACEC.* ***Safe Harbor*** *specializes in developing sustainable restoration strategies for coastal resource systems.* ***Safe Harbor Educational Publications*** *are self-funded by Safe Harbor. to support our educational efforts, please contact gordonpeabody@gmail.com*

I. General Strategies for Stabilization

Steep, (45 degree) and Very Steep (60 degree) de-vegetated slopes left unprotected are fair game for rain-generated storm water erosion. Gravity-driven sheet flow is generated directly by the slope itself and indirectly by contributing sources upslope. Gravity collects downslope sheet flow into accelerating point sources. The weight of this mathematically amplified, liquid-sandpaper displaces soil, causing destruction primarily through erosion and secondarily through deposition. Downslope discharge often flows into wetlands. Vegetation growing in groundwater fed wetlands may be sensitive to surface discharge and deposition. Chronic deposition of sediment and silt will smother wetland vegetation. Reduced performance of wetland resources degrades habitat and invites potential regulatory consequences.

1. Assessment: Study the problem and the dynamics between elements of your problem: hydrology; slope; and habitat. Study and identify linkages between primary and secondary sheet flow sources and impacts. Then study adjacent, performing slopes that can be incorporated as a model for your project.

2. Get Measurements: Crest-to-foot and side-to-side slope width measurements will assist in calculating materials you will need. We usually divide large areas and long slopes into smaller, easier-to-manage work areas.

3. Address Contributing Flow: the shortest path to successful steep slope erosion control is removing upslope contributions before they reach the slope crest. We recommend "Smart Growth" and "Low Impact Development" (LID) Guidelines for low profile, low impact and low maintenance groundwater infiltration systems such as swales, dry wells, drip lines, filter strips and retention basins. Many of these sustainable, storm water management systems are described in: http://safeharborenv.com/2010/10/03/good-neighbor-storm-water-booklet-now-available/

4. Linkage to Scale: For a system to become sustainable, it should be modeled to mimic adjacent systems, not only in vegetation but also in soil profiles. Native compost/mulch, top cover and plantings should reflect similar, adjacent habitat.

5. Select Stabilization Technique: Carefully review options (sections II. and III.) for your site. Being able to address site specificity is a key to successful stabilization.

6. Consider Native Transplants: Native transplants have high survivability, if they include the native geomass they are growing in—incorporate the soil mass with compatible microorganism community, pH and nutrient values.

7. Limited Watering: Native vegetation can endure drought but during the first growing season, early root growth is developing. In times of drought, limited watering may be necessary. By the time leaves have begun to droop, damage may have already occurred. The bioengineered system provides a degree of moisture protection to roots. Hand watering is less efficient than timer operated drip hose irrigation but drip irrigation requires more initial effort. Water system decisions are site specific but may need to be "built in" to protect ecological and financial values.

8. Chemical Use: As a matter of policy, Safe Harbor does not use herbicides, pesticides or fertilizers. These unnatural fertilizers create vegetation that is chemically more attractive to insects and encourages invasive plants. They may also destabilize the density of nitrogen-fixing bacteria in roots, making plants "fertilizer dependent". Indigenous compost and mulch, with healthy, diverse microorganism and micro-invertebrate communities, provide a sustainable flow of nutrients. Vegetation consumed as a food source by native insects, small mammals, birds and herbivores, transfers critical ecological energy from plant biomass to animal biomass.

9. Sustainable Vegetation: After three years, bioengineered native vegetation systems will become increasingly more sustainable. This will reflect increased stabilization and infiltration performance. Some reseeding and replanting may be necessary. Sustainable slope stabilization systems mimic the simplicity of natural systems, using infiltration benches and native vegetation, to create high performance results.

10. Managing Invasive Vegetation: Invasive vegetation shows up in recently disturbed areas. Invasives exhibit exceptional growth rates, out-competing slower-growing native vegetation for light, moisture and nutrients. Many types of invasives also chemically interfere using root chemicals (allopathic). During the first year, we often allow invasives to contribute to slope stability, cutting them at the base before they seed and removing root and lower stem by hand when slope vegetation is more stable. Invasive vegetation management should be a component of slope stabilization. Without proper management, invasive canopy will characteristically block sunlight from stabilizing native vegetation at ground level, creating erosion potential.

12. Toe-of-Slope Control: Toe-of-slope mitigations may require temporary use of one or more erosion control systems to temporarily control toe erosion (double-staked straw bales, silt fences with extra stakes, and/or ground stapled biologs).

13. Support Regulations for Storm Water Protection: Uncontrolled upslope development, with impervious roofs, hardscape alterations to grade elevations and impacts to stabilizing vegetation will alter the nature (direction, volume and velocity) of storm water discharge. Planning and Conservation regulators need support in developing natural storm water management systems. Proper infiltration contributes to sustainable water resources. Low Impact Development (LID) and "Smart Growth" recommends storm water to ground water recharge as close to the source as possible.

II. Techniques for Stabilizing Steep Slopes

Beginning of restoration pictured at left; same area 4 months later at right.

1*. Control Vertical Access*: Vertical foot traffic creates impacts that are avoidable. A person walking downslope, through sand, displaces his or her own bodyweight every ten feet. We recommend using extension ladders to accommodate slope access. Extension ladders easily accommodate slopes 40 to 90 feet long. We recommend using oak stakes to secure the ladders every 20 feet, to prevent sliding. Also consider the option, where possible, of accessing the area from the bottom of the slope and working up.

2. Slope Preparation/Benching: Create "benched" infiltration terraces about a foot wide: we use shovels or boots to level them. These low-impact, horizontal line terraces should be inclined, to lean back into (or cant into) the slope. This technique will slow down, retain and infiltrate storm water. For 30° slopes, the infiltration lines can be spaced 8 feet apart. A 45° slope can accommodate infiltration lines 6 feet apart. Variable percolation rates should be a factor in determining spacing and depth of benches. Each bench wants to retain storm water from the raw slope immediately above it. As the slopes become more vegetated, the benches will also fill in with vegetation, transitioning the slope performance from mitigation to sustainable.

3. Control Horizontal Access: Use these terraces for access. The horizontal, benched terraces provide useful access paths for planting and mitigation work across the width of the slope.

4. Apply Indigenous Compost: Local, indigenous compost (fully decomposed indigenous plant material or compost which has been allowed to heat up enough to neutralize invasive seeds) is spread across the slope and gently raked into the raw, upper two inches of the slope. The profile should reflect native habitat. This layer contributes to sustainability by providing a diverse nutrient/microorganism community.

5. Do Not Over Compost: More is not better. Excess nutrients will attract invasive vegetation (like free beer at a party: "you never know who will show up"). Over-composting also invites downslope liabilities with excess nutrient transport.

6. Apply Indigenous Mulch: A thin layer of locally available mulch (semi-composted, indigenous plant material) reflecting the native habitat, should be spread over the compost layer. Straw mulch (but *never* hay with seeds) may be used in this layer. This creates a bioengineered layer that protects new roots from atmospheric moisture and temperature spikes. Layering also contributes to sustainability by providing micro invertebrate and insect biodiversity.

7. Native Seeding**:** Seed establishment is enhanced by planting during native germination windows. Re-seeding may be required during the first two growing seasons. Sow locally appropriate, Conservation Mix or collected seed into the net/mulch/compost. Many native grasses need a full year to begin performing.

8. Do Not Over Seed: More is not better. Over seeding will result in nutrient depletion from over competition. This seed mix is only intended as an initial stabilizer. Thick grass performs poorly by encouraging runoff.

9. Stabilize With Jute Netting: Natural fiber jute netting temporarily stabilizes soil structure by performing as a root/stem system and native seed capture grid. We recommend pre-cutting the four foot wide netting in 20 to 30' lengths. Two person installation teams help avoid destabilizing the previously completed surface layers. Install the upper netting edges along the outer edge of each infiltration terrace. On shallow slopes, we may only use a single width of netting, installed directly beneath each terrace.

10. Secure the Netting: Ground staples secure the top and bottom edges. Install staples on the vertical plane, not perpendicular to the slope, at 4-foot offset centers. Staple the center of the netting every 4'. We use biodegradeable cornstarch staples.

11. A Note on Bioengineering: The upper soil layer will reflect atmospheric moisture and temperature extremes. Intentionally constructed (bioengineered) layers provide protective envelopes from these moisture and thermal spikes for stable root growth. Jute netting seems to contribute best to overall system performance when used above the mulch layer and just below any top cover, which may electively be used (see #4 under General Strategies for Stabilization).

12. A Note on Biodiversity and Micro Habitats: Consistent profiles should be avoided. Nature is sporadic; we want to mimic this natural randomness. Thus, inexactness in the application of slope layers, and lumpy, articulated surfaces should be expected. These features create microhabitats, which contribute to plant and insect biodiversity. Site biomass, in the form of downed tree limbs and branches, can also contribute to slope structure and habitat diversity.

13. *Native Plantings:* Planting during seasonal moisture periods mimicks native germination windows and enhances survivability. Indigenous plantings and plugs, reflecting native vegetation diversity and density, can be directly dug in. Upslope plantings allow gravity to assist in downslope reseeding.

14. Use of Top Cover: (See images below) More is not better. Over covering blocks sunlight, reduces air exchange and redirects rainwater. Lightly spread a thin top covering of indigenous leaves, grass, evergreen needles or new straw across the netting. Target 40 to 80 percent slope coverage. Study adjacent stabilized slopes to determine appropriate composition and coverage (see #4 under General Strategies for Stabilization). Top cover enhances the bioengineered stability envelope, protecting against thermal and moisture spikes.

III. Two Techniques for Very Steep Slopes

1. Working on Very Steep Slopes: The interaction of effective infiltration strategy and successful native vegetation is necessary for sustainable stabilization on Very Steep Slopes. We have presented two, proven, illustrated systems for your consideration. We do not recommend mixing these systems. A higher level of attention is necessary when physically performing mitigations on Very Steep Slopes.

2. Control Vertical Access: Vertical foot traffic may create irreversible erosion impacts, which are avoidable. Even walking on the flats of your soles will risk destabilizing surface integrity. Use extension ladders to provide vertical access. They can be paralleled to access sequential areas. Extension ladders easily accommodate slopes 40 to 90 feet long. We recommend using oak stakes to secure the ladders every 10 feet on very steep slopes, to prevent sliding and where possible consider access from the bottom of the slope.

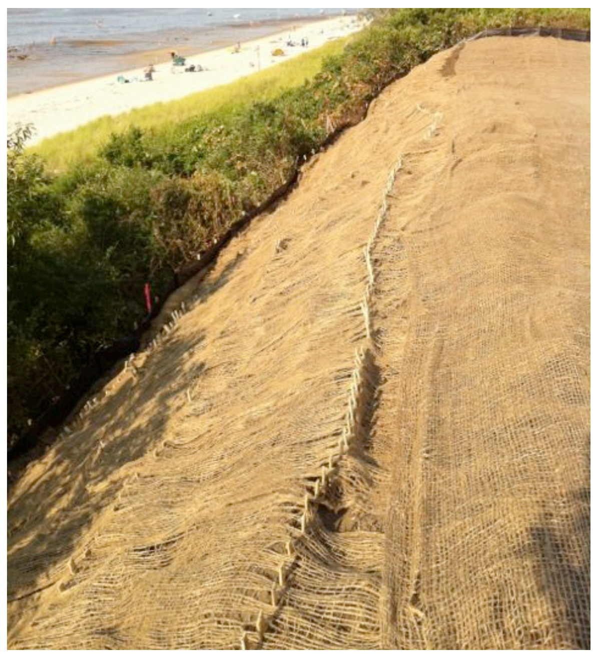
 

***3. Very Steep Slopes may be inappropriate for benching*:** Benching may risk destabilizing overall surface performance and integrity.

***4. Control Horizontal Access*:** Use ladders for horizontal access. These need to be carefully set down, using control ropes, as shown in the image. Once these are staked in place every ten feet (stakes driven vertically not perpendicular), they provide a productive work platform. Horizontal and vertical ladders can be joined to create a working grid to access the entire slope without stepping on slope surface

<u>Technique One</u>: Very Steep Slope Stabilization with Fence and Netting:
Lines of thin slat fencing 8-10 inches high are cut from snow fencing. A fifty-foot long roll of 4 foot snow fence will produce five sections (250 feet) of 8-10 inch high fence, with one line of connecting wire per section. Lines of this fencing are set vertically into the slope using rubber mallets. The fence lines are spaced approximately 4-6 feet apart.


Several inches of native compost are added gently to the slope. Jute netting is laid down and ground-stapled over the compost, allowing fence slats to show through.

At this point we usually do an initial planting of potted native plants. If social and permitting restrictions require us to work under threat of drought, we include a temporary drip irrigation system, which goes on with a timer, 1 hr. each morning.

After the first planting and installation of drip hoses we blow in native mulch over the site, about 2 inches thick. Using the mulch blower limits our liabilities from over-activity on very steep slopes. This mulch layer provides a safety envelope to prevent atmospheric moisture and temperature spikes from impacting new root growth.

Once the temporary stabilization system of short fence, compost, netting and mulch is in place, the slope assumes a greater stability and we finish planting with native plugs and potted native vegetation, mixing soft and woody stems for diversity.

By the end of the first full growing season, a high degree of sustainable performance was evident in the case study shown here, above and below.

<u>Technique Two</u>: Very Steep Slope Stabilization with Articulation-Shelving: Very Steep Slopes may be destabilized by benching and we do not recommend attempting that technique. Some coastal habitats are characterized by low-density vegetation but high percolation geomass. Stabilization techniques in these areas should focus on minimizing and mitigating storm water sheet flow. We recommend an innovative technique we refer to as "Slope

Articulation", or "Shelving". This innovative technique creates an infiltration matrix of multiple small (24"-36", tilted into slope) shelves, randomly placed over the slope surface. Cumulatively, these articulated areas perform using the same principles as benching, without inviting cross slope consequences.

24 inch shelving, created with a trowel. Overburden forms downslope berm.

We often utilize some but not all of the shelving, to plant native vegetation. This enhances storm water retention and infiltration performance. This shelf could use more back slant.

IV. Specific Techniques on Eroding Oceanside Coastal Banks

Eroding Coastal Banks are a natural part of the Coastal Process on Cape Cod.

1. When beaches erode, the lower section of a Coastal Bank, known as the "toe", will erode (collapse) to re-nourish the beach. When the toe erodes, the Coastal Bank will erode to form a new toe.

2. Interfering with this natural, gravity-driven process may generate unexpected and expensive consequences. *We recommend working with this natural process: take advantage of opportunities to maximize stability and minimize unnecessary erosion by linking native vegetation into the erosion process.*

3. Planting vegetation on Coastal Banks requires ladder access from the bottom up. We use a single ladder for access but do not recommend top down planting.

4. We recommend using salt-tolerant, native species such as beach grass and Bayberry, which continue growing if buried by sand movement.

5. We use five foot, triangular planting areas, with the triangle pointed down slope. These planting triangles are spaced horizontally, 20 feet apart. One series of triangles are plantings 10 feet above the beach and a second series are planted 20 feet and then 30 feet above the beach.

6. As part of Cape Cod's coastal process, when erosion occurs on the beach, the toe of the bank will erode to renourish the beach. When the toe is gone, a section of bank will collapse and form a new toe. As this happens, vegetation is already established and contributes to stabilization of the new toe. *We are also currently experimenting with various "over the bank" nourishment strategies.*

In the foreground, this Ocean side coastal bank has a stable, vegetated toe, with no beach; A section of bank with no toe or beach is next to that; In the background is a section of bank with both a toe and a beach. These forms illustrate stages in the coastal process.

Because of the high rate of coastal bank erosion on the Ocean, many homeowners choose to move their home back from the bluff. This is often based on long term costs of $15,000 per year for nourishment or $50,000 for moving the house. There may be associated costs.

V. Specific Techniques for Stabilizing Eroding Bayside Coastal Banks

1. Understanding the Coastal Process is critical to protecting the coast.
The toe and bank need to be able to erode to protect the overall, coastal beach system. Some homeowners on the bayside of Cape Cod have invested heavily in semi-engineered alternative systems, replacing sand but also building a zigzag fence along the base of the Bank. Once surge water gets inside these fences, the slats restrict outflow. This creates acceleration of water, which amplifies the rate of material transport out through the fences.

Over wash trapped by fencing, increases exit velocity, causing sand erosion.

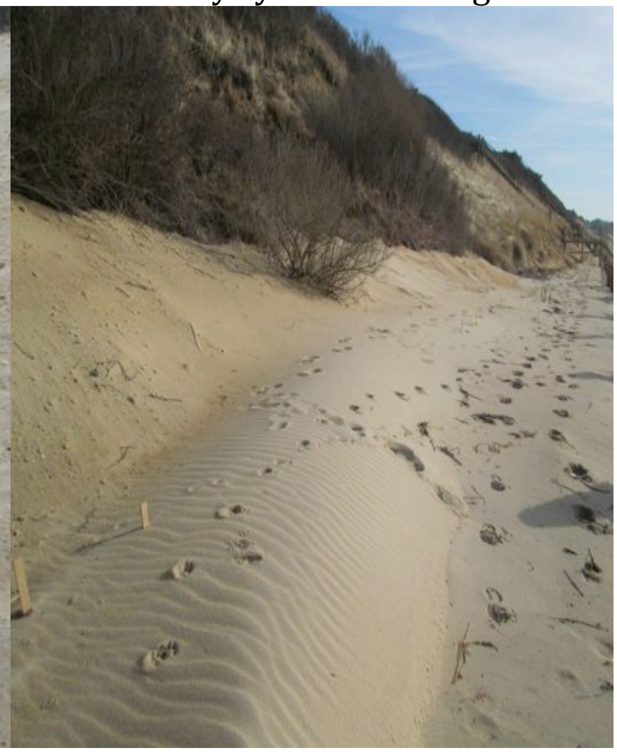
On eroding, Bayside coastal banks, we recommend using nourishing to create a new toe. This works with the coastal process, protecting the bank by eroding during storms, instead of the bank itself eroding.

Nourished toes can be planted with stabilizing beach grass and use biomimicry sand collection to gain additional, wind blown sand.

Biomimicry sand collection system is shown in the next several images. This system can enhance nourished areas or be used as a "stand alone" system to reduce net loss. We recommend nourishment with Biomimicry.

For Biomimicry info http://safeharborenv.com/services/biomimicry-creating-land-from-air/

Biomimicry in place to create new toe Biomimicry system creating new toe



Images below: After 5 storms, nourished bank on left, un-nourished on right.

Our alternatives analysis for Bayside coastal bank stabilization is not fully presented here. We have expressed the preferred alternative of nourishment, based on Ecological and Financial performance. The Social factor regarding our preferred alternative remains unresolved. Coir rolls and drift fence semi-structures seem to offer the perception of protection but have yet to demonstrate performance compared to nourishment. (Both coir and drift fences are always required to have sand nourishment as well). Each coastal community has permitting guidelines for activity on coastal bluffs and banks.

<u>Alternatives Analysis: Stabilizing Bayside Coastal Banks</u>

<u>DEFINITIONS</u>:

Coastal Banks have physically linked components: the coastal bluff; escarpment (face); toe.
Coastal Beaches have physically linked components: upper beach; lower beach; and intertidal beach.
Sand Bars have physically linked components: outer bar; inner bar; and rip channels.
Coastal Profile is a term that physically links all of these components (sand bars, beaches and banks) together.
Site Specificity integrates bathymetry of sand bars, articulations of beaches and the heights and composition of banks for each particular area.
Coastal Process occurs when coastal energy (wind; waves; tide; gravity) interacts with the coastal profile.
Coastal System links all of the physical components and all of the energy components as inclusive in a single system. When the Coastal Profile interacts with the Coastal Process, these linked elements respond as a System.

LINKAGE TO SCALE: The Big Picture

Understanding the *Coastal Process* is critical to understanding and responding to coastal erosion. The forms of energy flowing through the system are interacting with profiles and constantly reshaping the Cape by removing sand (erosion) from one area and placing it (deposition) elsewhere. The transit path of this moving sand forms underwater profiles, reducing storm wave height along the coast. Specific, decadel patterns of alternating erosion and deposition, dynamic equilibrium, overall net loss or overall net gain, may characterize each area of coastline.

Understanding the role of *Uncertainty* is critical to understanding and responding to coastal erosion. The Bayside coasts of Cape Cod are characterized by annual, variable (usually minimal) net loss. This may play out as decadal, zero net loss, followed by cumulative net loss during a single year. The uncertain strength, track, timing and development of energy systems contributing to erosion rates is determined by hemispheric scale events and subject to modeling failure.
Understanding the role of Synergy is important when responding to coastal erosion. When a synergy of the uncertain variables of energy integrate, such as

onshore wind and waves at the top of the tide or surge, exponential erosion is possible. However, uncertainty only infrequently synergizes these energies.

Understanding the role of Anomalies is important when responding to coastal erosion. Isolated erosion events occur from random (or point) synergy. These may be the result of weather anomalies; Short time linkages to seasonal wind and wave patterns; The state of the tide during storm events; and or the diurnal, bidirectional tidal current, moving millions tons of water each day; Possible Climate Changes.

Understanding Linkage is critical when responding to coastal erosion. In *Coastal Systems*, sloped beaches absorb storm wave energy. Excess energy erodes the beach, transforming sloped beach profiles to horizontal. Horizontal beach profiles allow undiminished storm waves to access the toe of the coastal bank. The toe now absorbs wave energy and erodes. Materials from the toe move seaward to replace beach materials. Once the toe profile has transitioned to horizontal, storm wave energy (depending on the state of the tide) may access the coastal bank directly. The bank will absorb wave energy and a section will collapse, creating a new toe to restore the profile.

REVIEW:

Let's review some of the relevant principles of the *Coastal Process*: *Coastal Profiles* respond to erosion as *Linked Systems;* The *Coastal System* will erode at *differential rates over time* (based on previously identified variables and constants); But the process will produce *uniform erosion rates* during any single storm event; Over time all sand on this section of coast will move north; new sand will enter and transit the system from erosion in the south (up drift) and the partial collapse of sections of coastal bank..

***Coastal Systems* are linked together along the coastline**. Each system (up drift to the south) erodes and passes sand along for varied use by the next system (down drift to the north). This is referred to as "linkage to scale". A question to consider in seeking sustainable solutions to coastal erosion: What will the consequences be with "*Linkage to Scale*"? How will your solution impact (or be impacted by) the overall coastal process?

Only a renourished beach and toe can protect a coastal bank but sand may be in short supply on the inside of the Cape. This is due to several factors: To the south (up drift), perpendicular coastal erosion control structures (groins, jetties) interrupt the north (down drift) flow of sand; The lack of nourishment requirements for up drift, pre existing coastal bank structures (sea walls, revetments); The lack of sand in transit also contributes to less storm wave protection. Together with seasonal erosion patterns, these factors have the potential to create a chronic, net loss of sand along the western coast of Cape Cod. Anything diminishing up drift supply or transit, will, by default, result in higher coastal bank collapse rates

EROSION RESPONSE ALTERNATIVES:

Alternative 1: No action

a). Costs: (None)

b). Consequences: Continuing pattern of coastal erosion along adjacent coastline will determine specific rate of erosion on this site.

Alternative 2: Coir Rolls

a). Costs: (Significant) Permitting; Coir materials; Helical anchors; Renourishment sand; Native vegetation; (Conservation Commission bylaw escrow required in some coastal communities to assure continued renourishment $5000).

b). Consequences: Coir is not suitable for velocity zones (waves) or recommended for coastal use without nourishment. Ongoing renourishment, possible replacement and maintenance may be necessary (dependent on continuing pattern of coastal erosion along several miles of adjacent coastline that will determine specific rate of erosion on this site). If connected coastline does not move back at the same rate, an anomaly is created which may impact the coastal process.

Alternative 3: Zig-zag Fence

a). Costs: (Intermediate) Permitting; Fence materials; Excavation; Sand materials; Native vegetation.

b). Consequences: Fencing resistance to water flow results in impacts and replacement of fences (dependent on continuing pattern of coastal erosion along several miles of adjacent coastline that will determine specific rate of erosion on this site). Storm waves will still have direct access. When waves overwash these fences, the slats restrict outflow. This increases velocity of out flowing water, increasing sand transport out through the fence. This results in net loss of renourishment sand.

Alternative 4: Renourishment

a). Costs: (Lowest) Permitting; Sand materials; Native vegetation.

b). Consequences: Ongoing renourishment and replanting may be necessary (dependent on pattern of coastal erosion along adjacent coastline, which will determine specific rate of erosion on this site).

Alternative 5: Relocation *(refer to cost benefit analysis)*
Cost/Benefit Analysis of Alternatives:

If we are installing any sort of coastal bank erosion control structure or semi structure (to "protect" the coastal bank by not allowing it to erode) we are required by regulatory authorities to provide sand (nourishment) that would be available for use by the *Coastal System* during erosion events. All coastal bank erosion control systems (hard solution, soft solution) are now required to provide a final layer of sand nourishment for use by the coastal system during erosion conditions.

Any alternative chosen is required to provide the nourishment layer. In considering the costs and consequences of the alternatives (2: Coir Rolls and 3: Zig-Zag Fence): renourishment would still be necessary and required following any erosion event; The overall effectiveness of alternative 2 or 3 would ultimately be determined by actions on abutting properties on this section of coastline; Without participation from abutting properties in similar structures, these structures on your property could create an anomalous coastal profile; Anomalous coastal profiles tend to attract more wave energy, creating ongoing maintenance issues; and subsequent erosion (scour) on abutting properties.

Findings:

Over a 30 year alternative analysis, it might be determined that dwelling relocation would be most cost effective. In the future, coastal towns may also establish linked coastal management plans that would provide opportunities for connected erosion control systems with uniform nourishment standards.

Recommendation:

We feel that Alternative 4: Renourishment, would be in the best medium-term interest*: Renourishment works with the coastal process. Since renourishment would need to be a part of any erosion control system, renourishment would constitute the most effective and cost effective response to protect property, if relocation is not practical. Planting native beach grass and/or biomimicry would contribute to stabilization and collection of new sand from seasonal storm winds.*

More information is available at **www.SafeHarborEnv.com**