



# Natural and Structural Measures for Shoreline Stabilization

## Living Shorelines

Innovative approaches are necessary as our coastal communities and shorelines are facing escalating risks from more powerful storms, accelerated sea-level rise, and changing precipitation patterns that can result in dramatic economic losses. While the threats of these events may be inevitable, understanding how to adapt to the impact is important as we explore how solutions will ensure the resilience of our coastal communities and shorelines.

This brochure presents a continuum of green to gray shoreline stabilization techniques, highlighting Living Shorelines, that help reduce coastal risks and improve resiliency through an integrated approach that draws from the full array of coastal risk reduction measures.

# Coastal Risk Reduction and Living Shorelines

## Coastal Risk Reduction

Coastal systems typically include both natural habitats and man-made structural features. The relationships and interactions among these features are important variables in determining coastal vulnerability, reliability, risk and resilience.

Coastal risk reduction can be achieved through several approaches, which may be used in combination with each other. Options for coastal risk reduction include:

- **Natural or nature-based measures:** Natural features are created through the action of physical, biological, geologic, and chemical processes operating in nature, and include marshes, dunes and oyster reefs. Nature-based features are created by human design, engineering, and construction to mimic nature. A living shoreline is an example of a nature-based feature.
- **Structural measures:** Structural measures include sea walls, groins and breakwaters. These features reduce coastal risks by decreasing shoreline erosion, wave damage, and flooding.
- **Non-structural measures:** Includes modifications in public policy, management practices, regulatory policy and pricing policy (e.g., structure acquisitions or relocations, flood proofing of structures, implementing flood warning systems, flood preparedness planning, establishment of land use regulations, emergency response plans).

The types of risk reduction measures employed depend upon the geophysical setting, the desired level of risk reduction, objectives, cost, reliability, and other factors.

## SAGE – Systems Approach to Geomorphic Engineering

USACE and NOAA recognize the value of an integrated approach to risk reduction through the incorporation of natural and nature-based features in addition to non-structural and structural measures to improve social, economic, and ecosystem resilience. To promote this approach, USACE and NOAA have engaged partners and stakeholders in a community of practice called SAGE, or a Systems Approach to Geomorphic Engineering. This community of practice provides a forum to discuss science and policy that can support and advance a systems approach to implementing risk reduction measures that both sustain a healthy environment and create a resilient shoreline.

SAGE promotes a hybrid engineering approach that integrates soft or ‘green’ natural and nature-based measures, with hard or ‘gray’ structural ones at the landscape scale. These stabilization solutions include “living shoreline” approaches which integrate living components, such as plantings, with structural techniques, such as seawalls or breakwaters.

Living Shorelines achieve multiple goals, such as:

- Stabilizing the shoreline and reducing current rates of shoreline erosion and storm damage;
- Providing ecosystem services (such as habitat for fish and other aquatic species) and increasing flood storage capacity; and
- Maintaining connections between land and water ecosystems to enhance resilience.

In order to determine the most appropriate shoreline protection technique, several site-specific conditions must be assessed. The following coastal conditions, along with other factors, are used to determine the combinations of green and gray solutions for a particular shoreline.

**REACH:** A longshore segment of a shoreline where influences and impacts, such as wind direction, wave energy, littoral transport, etc. mutually interact.

**RESILIENCE:** The ability to avoid, minimize, withstand, and recover from the effects of adversity, whether natural or man made, under all circumstances of use. This definition also applies to engineering (i), ecological (ii), and community resilience (iii).

**FETCH:** A cross shore distance along open water over which wind blows to generate waves. For any given shore, there may be several fetch distances depending on predominant wind direction.

**PHYSICAL CONDITIONS:** The slope of the foreshore or beach face, a geologic condition or bathymetry offshore.

**TIDAL RANGE:** The vertical difference between high tide and low tide.

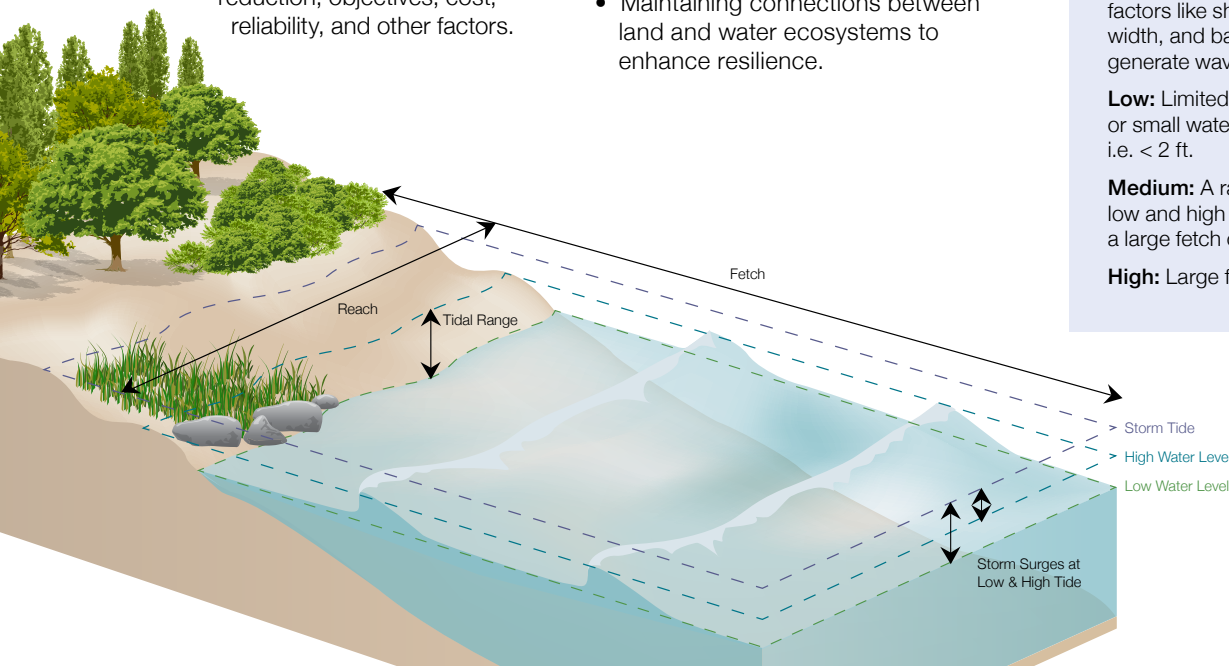
**STORM SURGE:** The resulting temporary rise in sea level due to the action of wind stress on the water surface and low atmospheric pressure created during storms which can cause coastal flooding. Surge is the difference from expected tide level. Storm tide is the total water level.

**WAVE ENERGY:** Wave energy is related to wave height and describes the force a wave is likely to have on a shoreline. Different environments will have lower or higher wave energy depending on environmental factors like shore orientation, wind, channel width, and bathymetry. Boat wakes can also generate waves.

**Low:** Limited fetch in a sheltered, shallow or small water body (estuary, river, bay) i.e. < 2 ft.

**Medium:** A range that combines elements of low and high energy (e.g., shallow water with a large fetch or partially sheltered) i.e. 2 - 5 ft.

**High:** Large fetch, deep water (open ocean).



# GREEN - SOFTER TECHNIQUES

Small Waves | Small Fetch | Gentle Slope | Sheltered Coast

## LIVING SHORELINE

### VEGETATION ONLY

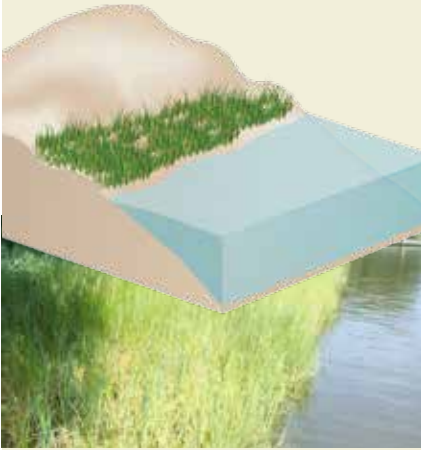


Photo Credit: Maryland Department of Natural Resources - Shoreline Conservation Service

Roots hold soil in place to reduce erosion. Provides a buffer to upland areas and breaks small waves.

#### Suitable For

Low wave energy environments.

#### Material Options

- Native plants\*

#### Benefits

- Dissipates wave energy
- Slows inland water transfer
- Increases natural storm water infiltration
- Provides habitat and ecosystem services
- Minimal impact to natural community and ecosystem processes
- Maintains aquatic/terrestrial interface and connectivity
- Flood water storage

#### Disadvantages

- No storm surge reduction ability
- No high water protection
- Appropriate in limited situations
- Uncertainty of successful vegetation growth and competition with invasive

Initial Construction: ●  
Operations & Maintenance: ●●

### EDGING



Photo Credit: Partnership for Delaware Estuary

Structure to hold the toe of existing or vegetated slope in place. Protects against shoreline erosion.

#### Suitable For

Most areas except high wave energy environments.

#### Vegetation\* Base with Material Options

- (low wave only, temporary)
- "Snow" fencing
  - Erosion control blankets
  - Geotextile tubes
  - Living reef (oyster/mussel)
  - Rock gabion baskets

#### Benefits

- Dissipates wave energy
- Slows inland water transfer
- Provides habitat and ecosystem services
- Increases natural storm water infiltration
- Toe protection helps prevent wetland edge loss

#### Disadvantages

- No high water protection
- Uncertainty of successful vegetation growth and competition with invasive

Initial Construction: ●●  
Operations & Maintenance: ●●●

### SILLS

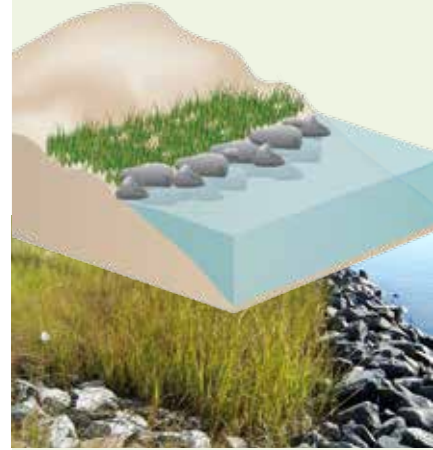


Photo Credit: Maryland Department of Natural Resources - Shoreline Conservation Service

Parallel to existing or vegetated shoreline, reduces wave energy and prevents erosion. A gapped approach would allow habitat connectivity, greater tidal exchange, and better waterfront access.

#### Suitable For

Most areas except high wave energy environments.

#### Vegetation\* Base with Material Options

- Stone
- Sand breakwaters
- Living reef (oyster/mussel)
- Rock gabion baskets

#### Benefits

- Provides habitat and ecosystem services
- Dissipates wave energy
- Slows inland water transfer
- Provides habitat and ecosystem services
- Increases natural storm water infiltration
- Toe protection helps prevent wetland edge loss

#### Disadvantages

- Require more land area
- No high water protection
- Uncertainty of successful vegetation growth and competition with invasive

Initial Construction: ●●●  
Operations & Maintenance: ●●●●

### BEACH



Photo Credit: Maryland Department of Natural Resources - Shoreline Conservation Service

Large volume of material placed outside of vegetated area. Widens shoreline.

#### Suitable For

Low-lying areas with existing sediment.

#### Material Options

- Sand

#### Benefits

- Expands shoreline
- Lower cost than other techniques
- Flexible
- Reduces erosion
- Provides habitat and ecosystem services

#### Disadvantages

- Requires regular maintenance
- No high water protection
- Approaches may be temporary
- Possible sedimentation

Initial Construction: ●●●●  
Operations & Maintenance: ●●●●●

\* Native plants and materials must be appropriate for current salinity and site conditions.

Initial Construction: ● = up to \$1000 per linear foot, ●● = \$1001 - \$2000 per linear foot, ●●● = \$2001 - \$5000 per linear foot, ●●●● = \$5001 - \$10,000 per linear foot, ●●●●● = over \$10,000 per linear foot  
Operations and Maintenance (yearly for a 50 year project life): ● = up to \$100 per linear foot, ●● = \$101 - \$500 per linear foot, ●●● = over \$500 per linear foot

# HOW GREEN OR GRAY SHOULD YOUR SHORELINE SOLUTION BE?

## BEACH NOURISHMENT ONLY



Photo Credit: USACE New York District Public Affairs

Volume of sand added from source to an eroding beach. The beach and moves the seaward.

### Suitable For

Low-lying oceanfront areas with existing sources of sand and sediment.

### Material Options

Sand with vegetation  
Can also strengthen dunes with:

- Geotextile tubes
- Rocky core

### Benefits

- Expands usable beach area
- Lower environmental impact
- Flexible strategy
- Redesigned with relative ease
- Vegetation strengthens dunes and increases their resilience to storm events
- Provides habitat and ecosystem services

### Disadvantages

- Requires continual sand resources for renourishment
- No high water protection
- Appropriate in limited situations
- Possible impacts to regional sediment transport

Initial Construction: ●●●●  
Operations & Maintenance: ●●

\$100 per linear foot  
\$10 per linear foot

## BEACH NOURISHMENT & VEGETATION ON DUNE

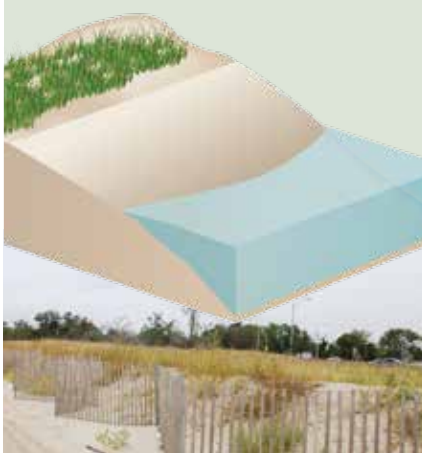


Photo Credit: USACE New York District Public Affairs

Helps anchor sand and provide a buffer to protect inland area from waves, flooding and erosion.

### Suitable For

Low-lying oceanfront areas with existing sources of sand and sediment.

### Material Options

Sand with vegetation  
Can also strengthen dunes with:

- Geotextile tubes
- Rocky core

### Benefits

- Expands usable beach area
- Lower environmental impact
- Flexible strategy
- Redesigned with relative ease
- Vegetation strengthens dunes and increases their resilience to storm events
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### Disadvantages

- Requires continual sand resources for renourishment
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- Possible impacts to regional sediment transport

Initial Construction: ●●●●  
Operations & Maintenance: ●●

## BREAKWATER

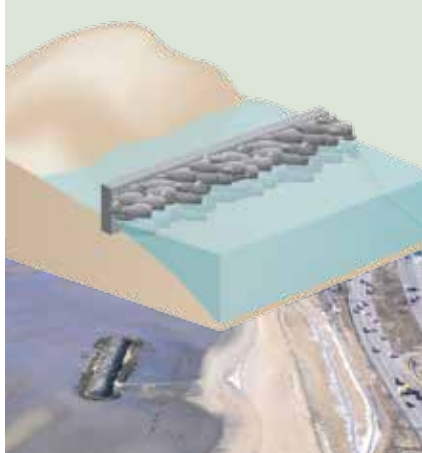


Photo Credit: USACE New York District Public Affairs

Offshore structures intended to break waves, reducing the force of wave action and encourages sediment accretion. Can be floating or fixed to the ocean floor, attached to shore or not, and continuous or segmented. A gapped approach would allow habitat connectivity, greater tidal exchange, and better waterfront access.

### Suitable For

Most areas except high wave energy environments often in conjunction with marinas.

### Material Options

- Grout-filled fabric bags
- Wood
- Armorstone
- Rock<sup>†</sup>
- Pre-cast concrete blocks
- Living reef (oyster/mussel) if low wave environment

### Benefits

- Reduces wave force and height
- Stabilizes wetland
- Can function like reef
- Economical in shallow areas
- Limited storm surge flood level reduction

### Disadvantages

- Expensive in deep water
- Can reduce water circulation (minimized if floating breakwater is applied)
- Can create navigational hazard
- Require more land area
- Uncertainty of successful vegetation growth and competition with invasive
- No high water protection
- Can reduce water circulation
- Can create navigation hazard

Initial Construction: ●●●●  
Operations & Maintenance: ●●●●

## GROIN



Photo Credit: USACE New York District Public Affairs

Perpendicular, projecting from shoreline. Intercept water flow and sand moving parallel to shoreline to prevent beach erosion and break waves. Retain sand placed on beach.

### Suitable For

Coordination with beach nourishment.

### Material Options

- Concrete/stone rubble<sup>†</sup>
- Timber
- Metal sheet piles

### Benefits

- Protection from wave force
- Methods and materials are adaptable
- Can be combined with beach nourishment projects to extend their life

### Disadvantages

- Erosion of adjacent sites
- Can be detrimental to shoreline ecosystem (e.g. replaces natural substrate with rock and reduces natural habitat availability)
- No high water protection

<sup>†</sup> Rock/stone needs to be

GRAY CAN BE GREENER: e.g., 'Living

Initial Construction: ●●●●  
Operations & Maintenance: ●●●●

# GRAY - HARDER TECHNIQUES

Large Waves | Large Fetch | Steep Slope | Open Coast

## COASTAL STRUCTURE

### REVTMENT

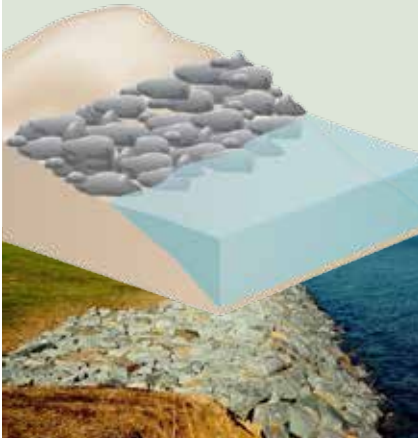


Photo Credit: Maryland Department of Natural Resources - Shoreline Conservation Service

Lays over the slope of a shoreline. Protects slope from erosion and waves.

#### Suitable For

Sites with pre-existing hardened shoreline structures.

#### Material Options

- Stone rubble<sup>†</sup>
- Concrete blocks
- Cast concrete slabs
- Sand/concrete filled bags
- Rock-filled gabion basket

#### Benefits

- Mitigates wave action
- Little maintenance
- Indefinite lifespan
- Minimizes adjacent site impact

#### Disadvantages

- No major flood protection
- Require more land area
- Loss of intertidal habitat
- Erosion of adjacent unreinforced sites
- Require more land area
- No high water protection
- Prevents upland from being a sediment source to the system

...e appropriately sized for site specific wave energy.

Initial Construction: ●●●●  
Operations & Maintenance: ●●

### BULKHEAD

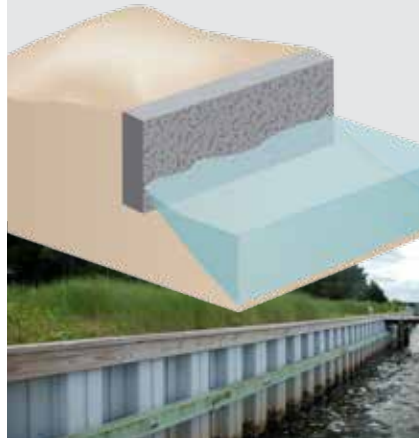


Photo Credit: North Carolina Department of Environment and Natural Resources

Parallel to the shoreline, vertical retaining wall. Intended to hold soil in place and allow for a stable shoreline.

#### Suitable For

High energy settings and sites with pre-existing hardened shoreline structures. Accommodates working water fronts (eg: docking for ships and ferries).

#### Material Options

- Steel sheet piles
- Timber
- Concrete
- Composite carbon fibers
- Gabions

#### Benefits

- Moderates wave action
- Manages tide level fluctuation
- Long lifespan
- Simple repair

#### Disadvantages

- No major flood protection
- Erosion of seaward seabed
- Erosion of adjacent unreinforced sites
- Loss of intertidal habitat
- May be damaged from overtopping oceanfront storm waves
- Prevents upland from being a sediment source to the system
- Induces wave reflection

Initial Construction: ●●●  
Operations & Maintenance: ●●

### SEAWALL

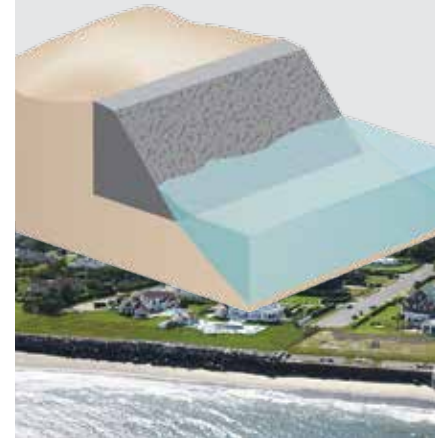


Photo Credit: USACE New York District Public Affairs

Parallel to shoreline, vertical or sloped wall. Soil on one side of wall is the same elevation as water on the other. Absorbs and limits impacts of large waves and directs flow away from land.

#### Suitable For

Areas highly vulnerable to storm surge and wave forces.

#### Material Options

- Stone
- Rock
- Concrete
- Steel/vinyl sheets
- Steel sheet piles

#### Benefits

- Prevents storm surge flooding
- Resists strong wave forces
- Shoreline stabilization behind structure
- Low maintenance costs
- Less space intensive horizontally than other techniques (e.g. vegetation only)

#### Disadvantages

- Erosion of seaward seabed
- Disrupt sediment transport leading to beach erosion
- Higher up-front costs
- Visually obstructive
- Loss of intertidal zone
- Prevents upland from being a sediment source to the system
- May be damaged from overtopping oceanfront storm waves

Initial Construction: ●●●●  
Operations & Maintenance: ●●●

...g Breakwater' using oysters to colonize rocks or 'Greenwall/Biowall' using vegetation, alternative forms and materials

# Is a Living Shoreline a Good Fit for What I Need?

## Living Shorelines achieve multiple goals such as:

- Stabilizing the shoreline and reducing current rates of shoreline erosion and storm damage
- Providing ecosystem services, such as habitat for fish and other aquatic species and increasing flood storage capacity
- Maintaining connections between land and water ecosystems to enhance resilience

Site-specific conditions will influence your choice of shoreline protection technique (ex: wave energy level, fetch lengths, rate and pattern of erosion, etc). Here are some additional factors to keep in mind as you consider Living Shorelines.

## WHAT ARE THE BENEFITS?

- Erosion control and shore stabilization.
- Restored and enhanced habitat which supports fish and wildlife populations.
- Increased property values.
- Enhanced community enjoyment.
- Opportunities for education.
- Improved public access to waterfront through recreational activities such as fishing, boating and birding. Can be used to satisfy zoning and permitting requirement for waterfront development projects.
- Complemented natural shoreline dynamics & movement; increased resilience and absorption of wave energy, storm surge and floodwaters; and an adaptive tool for preparation of sea level rise.
- Improved water quality from settling or trapping sediment (e.g. once established, a marsh can filter surface water runoff or oysters can provide coastal water filtration).

## WHAT ARE SOME CHALLENGES?

- Uncertainty in risk because of lack of experience of techniques.
- Public funds are often tied to government permit compliance.
- Permitting processes can be lengthy and challenging. The existing regulatory process is centered on traditional “gray” or “hard” techniques. Regulators and project sponsors alike are learning how to design living shorelines projects. Talk with someone about your state’s permitting process or to hear about their experiences.
- It takes time to develop and test new shoreline protection methods.
- There may be land ownership constraints. Consider where federal and state jurisdiction for the water body starts and ends.
- In urban environments, there is limited land (bulkheads may seem like the only option), a variety of upland uses (industrial past use may have left legacy contaminants) and high velocity waters.
- The overall sediment system needs to be taken into account to protect neighboring properties from experiencing starved down drift shorelines or other consequences as a result of a project.
- Lack of public awareness of performance and benefits of living shorelines.
- Not all techniques have the same level of performance or success monitoring. Less practiced techniques may require more monitoring.

## WHAT INFLUENCES COST?

- The materials chosen for the project influence cost.
- Including green techniques can be cheaper than traditional gray techniques.
- Sometimes it’s possible to install the project yourself, other times you will need help from a professional.
- Long term maintenance is required as any landscape project (e.g. replanting may be needed after a storm).

## HOW TO FIND OUT MORE

If you have a Living Shorelines permitting question, contact your state’s office of Environmental Protection, Conservation or Natural Resources, your coastal zone manager such as your state’s Department of State, as well as your local U.S. Army Corps of Engineers (USACE) district office.

If you would like science or engineering advice, or to talk to people who have experience studying or constructing living shorelines, reach out to some of the following: your local universities, your City’s Department of Planning and Department of Parks, Sea Grant Chapter, Littoral Society, The Nature Conservancy, The Trust for Public Land, The Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration (NOAA), USACE, engineering firms and other organizations that focus on your local waterfront.

These and other websites are good references to learn more about Living Shorelines:

SAGE  
[www.SAGEcoast.org](http://www.SAGEcoast.org)

NOAA Restoration  
[www.habitat.noaa.gov/livingshorelines](http://www.habitat.noaa.gov/livingshorelines)

USACE Engineer Research Development Center, Engineering with Nature  
[el.ercd.usace.army.mil/ewn](http://el.ercd.usace.army.mil/ewn)

USACE North Atlantic Division, National Planning Center of Expertise for Coastal Storm Damage Reduction  
[www.nad.usace.army.mil/About/NationalCentersofExpertise/CoastalStormDamageReduction\(Planning\).aspx](http://www.nad.usace.army.mil/About/NationalCentersofExpertise/CoastalStormDamageReduction(Planning).aspx)

Virginia Institute of Marine Science (VIMS) Center for Coastal Resources Management  
[ccrm.vims.edu/livingshorelines/index.html](http://ccrm.vims.edu/livingshorelines/index.html)

Coasts, Oceans, Ports & Rivers Institute (CORPI)  
[www.mycopri.org/livingshorelines](http://www.mycopri.org/livingshorelines)

The Nature Conservancy  
[www.nature.org/ourinitiatives/habitats/oceanscoasts/howwework/helping-oceans-adapt-to-climate-change.xml](http://www.nature.org/ourinitiatives/habitats/oceanscoasts/howwework/helping-oceans-adapt-to-climate-change.xml)



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