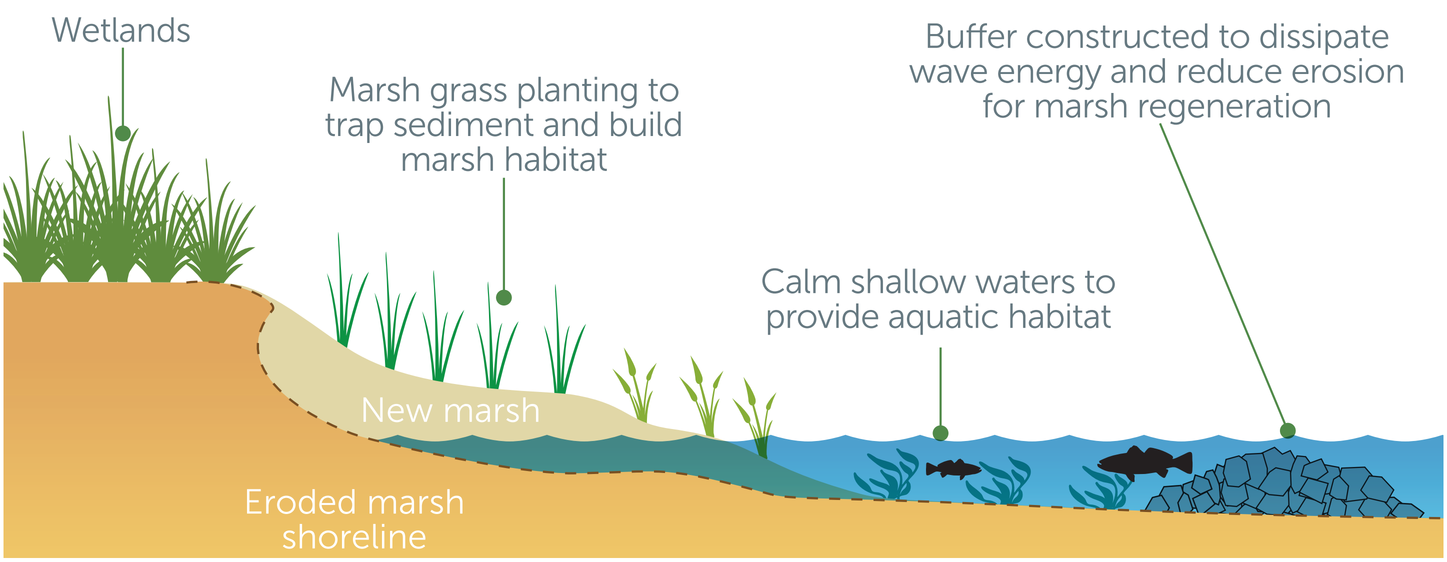
SHORELINE STABILIZATION RESILIENCY DESIGN GUIDE

About This Guide

Shoreline stabilization is one method to help reduce the risks posed by flooding and erosion. These risks to coastal communities are generally expected to increase with future relative sea level rise (RSLR) and more extreme weather events and coastal flooding. The purpose of this guide is to provide concise guidance on how to plan for and design coastal shoreline stabilization features, particularly under future RSLR scenarios.

Shoreline Stabilization Techniques

This section provides conceptual examples of shoreline stabilization techniques and typical cross-shore profiles.



*Shoreline stabilization features generally consist of **traditional armoring** (bulkheads, revetments, concrete seawalls), **living shorelines** with natural habitat features (horizontal levees, beach nourishment, tidal marshes, bluff vegetation), or **hybrids** of both (breakwaters with wetland vegetation, groins stabilizing a bay beach). The wave climate at a project site will be a key consideration. Living shorelines, for instance, are best suited for sheltered bays, rather than the open coast or bays with more dynamic wave environments.*

Each shoreline stabilization feature has benefits and drawbacks, and the type selected for a particular site depends on site-specific characteristics. The process to select, design, and build a particular alternative is described in the following sections. The graphic below summarizes different types of shoreline stabilization features and the overarching project goals that determine how they are typically used.

Flood Control

Traditional Armoring
- Seawall
- Levee
- Bulkhead

Flood/Erosion Control

Living Shoreline
- Bay or Gulf Beach
- Horizontal Levee
- Sand Berm or Dune
- Nearshore Engineered Reef
- Breakwater

Erosion Control

Living Shoreline
- Oyster Reef
- Wetlands
- Vegetation

Traditional Armoring
- Revetment
- Groin
- Bulkhead

Hybrid
- Vegetated Crib Wall
- Breakwater

Best suited for: High wave energy environment Low to moderate wave energy environment

Shoreline Stabilization Alternatives

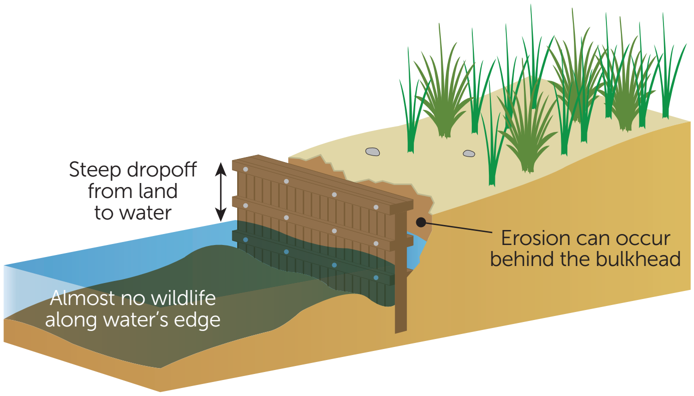
Conceptual renderings of select shoreline stabilization features

Traditional armoring is sometimes needed to provide sufficient shoreline protection, depending on the location and structural needs of the project site. When possible, consider hybrid solutions, such as living shorelines, that combine traditional armoring ("gray") and nature-based stabilization ("green") techniques.

Living shorelines are often better able to adapt to future conditions at the site, such as RSLR, have co-benefits like improved water quality and ecosystem functionality, and create habitat for terrestrial and aquatic species. Living shorelines are usually better suited for low wave energy environments, such as inland bays, rather than high energy environments like the open coast.

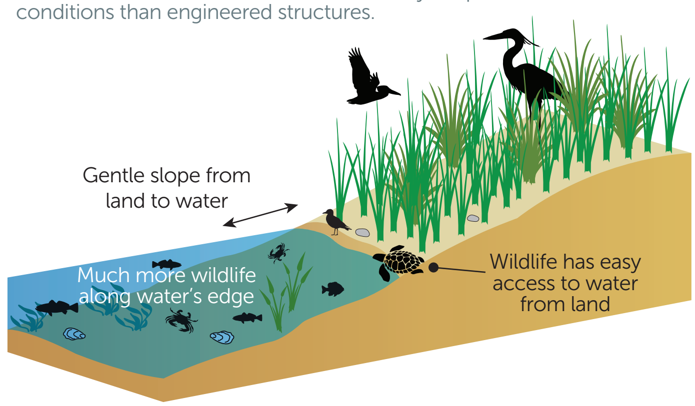
Bulkhead

Traditional engineered structures like bulkheads can sever the connection between the coast and water.



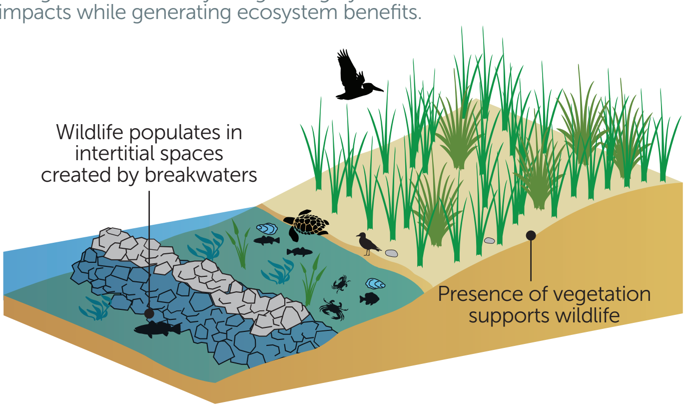
Vegetation Only

Nature-based features protect land from erosion, provide crucial habitat for fish and wildlife, and more readily adapt to future coastal conditions than engineered structures.



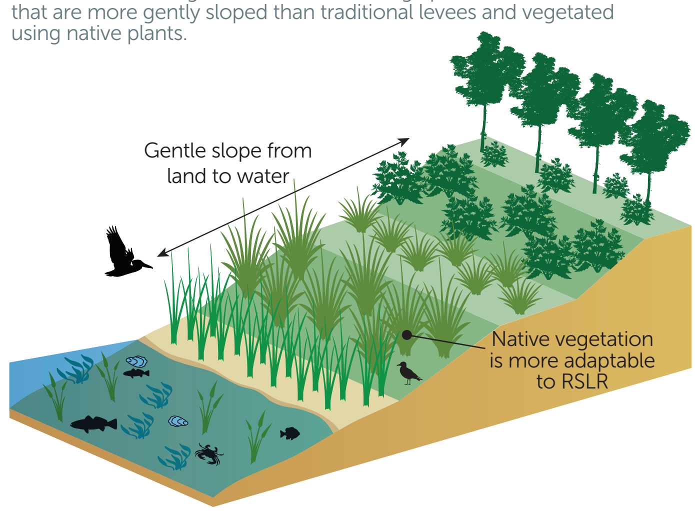
Living Shoreline *with Breakwater*

Living shorelines are hybrid green-gray features that reduce erosional impacts while generating ecosystem benefits.



Horizontal Levee

Horizontal, or "living," levees are storm surge protection features that are more gently sloped than traditional levees and vegetated using native plants.



**Above renderings adapted from https://www.delawarelivingshorelines.org/what-is-a-living-shoreline*

Costs

These costs are estimates for planning purposes only, and may require significant refinement based upon specific site conditions. Economies of scale may reduce costs for large-scale projects.

Construction	Annual Operations & Maintenance (O&M)
• Vegetation Only: $70-$115 per linear foot (LF) • Hybrid Shorelines (natural + structural): $120-$600+ per LF • Oyster Reef Restoration: $200-$400 per LF • Hardened Shoreline: $450-$1,000+ per LF • Beach Nourishment: $1.1 million per mile (includes O&M) • Dune Restoration: $2,000-$5,000 per LF	• Vegetation Only: <$100 per LF • Hybrid Shorelines (natural + structural): <$100 per LF • Oyster Reef Restoration: none • Hardened Shoreline: $100-$500+ per LF • Beach Nourishment: varies over project lifetime • Dune Restoration: $100-$500 per LF

Source: NOAA Nature-Based Solutions Installation and Maintenance Costs: *https://coast.noaa.gov/data/digitalcoast/pdf/nature-based-solutions-installation-maintenance.pdf*

Green and gray techniques to stabilize and protect shorelines

Technique	Permanence	Cost	Adaptability to RSLR*	Wave Energy Reduction	Benefits and Drawbacks
Vegetation Only	low	low	mod	low	**Benefits:** stabilizes and captures sediment, assists in additional plant colonization, improves habitat for marine and benthic species, aesthetics **Drawbacks:** low permanence unless coupled with structures, susceptible to RSLR
Vegetated Crib Wall	mod	low	low	low	**Benefits:** anchors sediment, assists in plant colonization, small footprint, unobtrusive, aesthetics **Drawbacks:** requires periodic adjustment for maximum effect, may become a safety or debris concern once deteriorated
Oyster Reef	mod	low	mod	mod	**Benefits:** provides natural estuarine habitat, recreation opportunities, and water filtration **Drawbacks:** may be limited in the amount of vertical relief attained
Nearshore Berm	low	mod	mod	mod	**Benefits:** can create additional protected space for habitats, such as marsh grass, and estuarine species, berms can act sacrifically and add sediment to the nearshore system **Drawbacks:** low permanence unless coupled with structures, susceptible to RSLR, may become a safety or debris concern once deteriorated
Beach Nourishment	low	high	high	high	**Benefits:** provides recreational opportunities, able to adapt to wave climate and recover from losses **Drawbacks:** causes disruption to beach microbiome, turtle nesting, and beach recreation during construction; cyclical sand losses are expected
Horizontal Levee	high	high	mod	high	**Benefits:** provides transitional estuarine habitat area, adaptive to RSLR, reduces need for structure height and hardening when compared to a traditional levee **Drawbacks:** requires larger footprint than a traditional levee to construct, requires maintenance
Nearshore Engineered Reef	mod	mod	low	mod	**Benefits:** provides interstitial estuarine habitat **Drawbacks:** requires periodic adjustment for maximum effect, may become a safety or debris concern once deteriorated
Breakwater	high	high	mod	mod	**Benefits:** allows leeward sediment accretion, creates sheltered estuarine areas, can be coupled with natural features to create a living shoreline **Drawbacks:** downdrift & updrift erosion, may become a safety or debris concern once deteriorated
Revetment**	high	high	mod	mod	**Benefits:** anchors shoreline location, prevents upland erosion **Drawbacks:** downdrift erosion, disallows shoreline migration, vulnerable to flanking and scouring, difficult to permit
Bulkhead	mod	mod	low	mod	**Benefits:** anchors shoreline location, prevents upland erosion, small footprint **Drawbacks:** profile deflation; vulnerable to flanking, erosion, and overwash; disrupts aesthetics; cuts off upland habitat from water
Groin**	high	high	low	low	**Benefits:** updrift accumulation **Drawbacks:** downdrift erosion, vulnerable to flanking
Levee	high	high	low	high	**Benefits:** anchors shoreline location, flood and storm surge control **Drawbacks:** downdrift erosion, vulnerable to flanking and scouring, disruption to shoreline access during construction, requires maintenance, may require more armoring when compared with a horizontal levee
Seawall**	high	mod	low	high	**Benefits:** anchors shoreline location, prevents upland erosion, small footprint **Drawbacks:** profile deflation, downdrift & updrift erosion, vulnerable to flanking, vulnerable to destabilization from overwash, disrupts aesthetics, cuts off upland habitat from water, requires maintenance

"Green" (Softer) Techniques ↔ "Gray" (Harder) Techniques

*Adaptability refers to the ability of the technique to respond to impacts due to RSLR or to extend the lifetime of the project given RSLR
**Can only be constructed by a subdivision of the state to protect public infrastructure (with extensive permitting requirements)

Resiliency Considerations

When selecting and designing a shoreline stabilization feature, there are three broad aspects of resiliency to consider to determine the most effective technique for a particular site: resiliency to future RSLR and related impacts, existing and intended shoreline conditions, and planning for adaptive capacity. Resiliency measures will depend on the lifespan of the project. Many shoreline stabilization features have a lifespan ranging from ten to 50 years.

Future RSLR & Related Impacts	Existing & Future Shoreline	Adaptive Capacity
• Areas with critical infrastructure (e.g., roads, hospitals, utilities) located near the shoreline or having higher wave exposure will have a lower risk tolerance and will need more robust stabilization features to reduce risk. • Areas with no critical infrastructure near the shoreline or having lower wave exposure will have a higher risk tolerance. • Future RSLR may exacerbate nuisance flooding during high tides.	• Many coastlines have been heavily altered by development. • Living shorelines can provide more natural habitat and increase shoreline access to the public. • In contrast, traditional armoring is often associated with a loss of nearshore habitat, structure end effects that can cause residual erosion, and reduced access to the public. • Existing traditional armoring can in some cases be incorporated into a new living shoreline design.	• When considering future resilience to RSLR, it is important to design for future adaptive capacity. • **Adaptive capacity** includes **the ability to elevate or retrofit a feature if future RSLR is higher than anticipated**, or if flooding and erosion problems worsen. Future RSLR estimates over longer time frames (50-100 years) have higher levels of uncertainty. • Examples of increasing capacity include elevating the top of a seawall, placing an additional cap on a bulkhead, constructing a revetment to prevent toe scour, increasing vegetation, and elevating or widening a revetment or breakwater. • Living shorelines can inherently increase capacity by adapting to coastal changes. For example, living shorelines naturally adapt to shoreline migration, unlike hard structures.

Engineering

This section provides a general framework for the engineering steps needed to:

- *Select an appropriate shoreline stabilization from several alternatives.*
- *Design the feature to protect against future RSLR.*
- *Plan for future maintenance and potential retrofits.*

Different shoreline stabilization features have various benefits and drawbacks, and there is no one-size fits all approach. The process of selecting and designing a particular feature follows three steps.

Marsh grass planting for shoreline stabilization.

Overall Approach

Step 1

Site Assessment and Concept Development

A planner or engineer develops a comprehensive list of potential shoreline stabilization techniques for a particular site and then refines the list based on general characteristics of the site.

Step 2

Alternatives Analysis and Preliminary Design

Conceptual designs are developed for a few select alternatives with site-specific design criteria. Each alternative is evaluated based on various factors, such as cost and effectiveness.

Step 3

Final Design and Construction

An alternative is selected, designed, and built.

Engineering - Step 1

Site Assessment and Concept Development

In the first step, the engineer will prepare a comprehensive list of techniques to choose from for a particular site before recommending stabilization alternatives. The following general aspects should be considered for each site.

Site Design Criteria	Historical Erosion and Sediment Transport	Risk Tolerance
• Before evaluating, the engineer will first develop design criteria for the site. These criteria will largely be based on the risk tolerance identified in Step 1. • For a site where flooding and erosion might have severe impacts, use more stringent design criteria (such as a higher future RLSR estimate or more severe design storm predictions). • Often, design storm conditions are calculated based on specific return periods (e.g., 10-, 50-, or 100-year). Relatively extreme (≥50-year) storm conditions might be calculated at a site with a low risk tolerance. • At a site where flooding and erosion might not have severe impacts, less stringent design criteria might be used. For example, 10- or 25-year design storm conditions might be used and some wave overtopping and resulting nuisance flooding might be allowed for in the design and planning.	• Historical erosion trends will provide some insight into future erosion patterns. A site that is currently eroding will likely erode rapidly under future RSLR. A site that is mildly accreting or stable might undergo moderate erosion in the future. • Sediment transport, including expected inputs (sources) and outputs (sinks) that could impact the project, should be considered.	Each community or governing agency will have a specific level of risk tolerance to flooding and erosion for a particular site. • A **low risk tolerance** suggests that even small amounts of future flooding and erosion will not be tolerated. • A **high risk tolerance** implies that future flooding and erosion could be tolerated to a certain extent. A higher risk tolerance allows more flexibility and creativity in shoreline stabilization. • Living shorelines and limited development can increase risk tolerance.

Engineering - Step 2

Alternatives Analysis and Preliminary Design

In the second step, the engineer will conduct a more detailed evaluation to compare the different benefits and drawbacks of the shoreline stabilization techniques developed in Step 1. Conceptual designs will then be developed for each selected alternative based upon site-specific design criteria. Once a preferred alternative is selected, preliminary design may begin.

Project Performance Requirements	Resilience Goals	Future RSLR and Adaptive Capacity
• The specific vulnerabilities at a site (e.g., flooding, erosion, habitat loss, community impacts) should be matched with the project purpose. • Determine a target metric for performance, such as percent reduction in flood or erosion risk. • Consider using hydrid or living shoreline stabilization alternatives to improve the effectiveness of the selected alternative. • The project must be feasible, constructible, permit-able, and cost effective. • The selected alternative should avoid residual impacts, such as worsening downdrift erosion or flanking.	Examples include: • Targeted lifespan for the alternative, given future RSLR. • Alignment with local coastal plans and priorities. • Achieving co-benefits, such as restoring habitats, protecting a given species, or avoiding impacts to existing special habitats or aquatic sites. • Improving site aesthetics and public education or access. • Allowing adaptive capacity to be achieved in the future, after initial construction.	• The amount of RSLR considered for the design should be associated with a future time frame that also accounts for the lifespan of the feature. • RSLR projections to use for the Texas coastline can be found in the *Texas Coastal Resiliency Master Plan*. • All designs should include an adaptive capacity that allows the system to be modified in the future. • Retrofits, re-designs, and new construction should be timed with the expected lifespan of each shoreline stabilization feature or during a period of major maintenance to maximize the use of funding.

Engineering - Step 2

Alternatives Analysis and Preliminary Design

While establishing the design criteria, the engineer will determine the general layouts of each feature. Conceptual designs should then be developed following established design guidelines and criteria for each feature type and evaluated based on the following criteria:

Effectiveness	• Each shoreline stabilization design should be evaluated based on whether it can provide the required levels of flood and erosion protection. Although they may experience deterioration, some structures and features (like beach nourishments or revetments) can withstand certain levels of damage without failing. • Engineering analyses are used to predict how much damage or deterioration structures will sustain during design storm events. • Future wave runup, overtopping, and erosion can be calculated to establish setback distances for infrastructure.
Site Constraints	• Environmental constraints, such as existing habitat, may exist. • Different shoreline stabilization features have various profile shapes and footprints. • Generally, unarmored living shorelines are typically flatter and have a larger footprint while steeper slopes could require armoring over a smaller footprint to prevent erosion. • In project areas with limited space, living shorelines may not be feasible.
Constructability	• Each shoreline stabilization alternative requires different materials and machinery to construct. • The evaluation should examine whether each feature is buildable using available materials at given water depths and following standard, safe construction methods. • Lack of design guidelines or contractor experience to construct living shorelines may limit constructability.
Impacts	• Traditional, hard armoring structures are associated with accelerated erosion and loss of fronting beach along shorelines adjacent to the structures. • Living shorelines are associated with fewer adverse erosion impacts and increased shoreline access for the public. • Some agencies offer encourage or offer benefits for replacing failing hard armoring with living shorelines.
Cost	• Costs for shoreline stabilization features should be evaluated based on construction methods, equipment, and materials, ease of site access, and future monitoring and maintenance needs. • In general, living shorelines tend to be made of less expensive materials than traditional armoring and have lower construction and repair costs.
Monitoring and Maintenance	• All constructed shoreline protection features require future, periodic maintenance. Living shorelines can be dynamic but typically require less frequent maintenance than traditional structures. • Living shorelines may benefit from more frequent monitoring when compared to traditional structures to determine site impacts and to adaptively manage the project.
Permitting	• Living shorelines without complicating circumstances may apply for the Nationwide 54 U.S. Army Corps of Engineers (USACE) permit. • Related state and local permits may be required, such as the Texas Parks and Wildlife Department Permit to Introduce Fish, Shellfish, or Aquatic Plants into Public Waters. • Some structure types could be forbidden, highly discouraged, or require strict permits.
FEMA/USACE Accreditation	• Many communities participate in the National Flood Insurance Program. Constructing new shoreline stabilization features may have implications for flood hazard maps and flood insurance rates. • Communities participating in the Federal Emergency Management Agency (FEMA) Community Rating System (CRS) may earn credits for habitat protection. • The engineer should ensure that a designed feature is in alignment with federal and state laws and design guidance, as well as local ordinances.

Engineering - Step 2

Alternatives Analysis and Preliminary Design

In areas where a living shoreline is desired but not feasible based on the above criteria, a hybrid shoreline protection feature could be designed and built. Hybrid approaches blend aspects of traditional armoring and nature-based features to provide some of the benefits of natural shorelines, including increased habitat and shoreline access, with flood and erosion protection.

Hybrid Shoreline Benefits

Environmental	Societal
• Increased nearshore habitat • Increased biodiversity • Allows shoreline migration • Increased erosion protection	• Increased flood protection • Can be lower cost • Public shoreline access • Adaptive capacity for future RSLR can be included in design • Improved aesthetics and increased property values

Engineering - Step 3

Final Design and Construction

A single alternative should be selected after evaluating the conceptual designs. Final engineering design and planning for construction, post-construction monitoring, and maintenance may begin using the steps outlined below.

Designing and constructing a shoreline stabilization solution will include:

1. Developing site-specific design conditions and criteria, including future RSLR scenarios and level of protection provided **(Step 1)**.
2. Developing conceptual designs of multiple shoreline stabilization alternatives and evaluating each alternative based on specific criteria **(Step 2)**.
3. Selecting one alternative and developing refined engineering drawings and specifications.
4. Obtaining permits, potentially including a Coastal Boundary Survey and a GLO Surface Lease if located on state-owned submerged land.
5. Constructing the shoreline stabilization feature.
6. Conducting periodic inspections and maintenance to address damage and any unexpected impacts, such as residual erosion.
7. Continue to monitor site conditions, as needed, and identify future adaptive capacity and management considerations.Performance characteristics below may be improved by combination of techniques.

Additional Information and Resources

- **GLO Guide to Living Shorelines in Texas:** *https://www.glo.texas.gov/coast/coastal-management/forms/files/living-shoreline/living-shorelines-in-texas.pdf*
- **Living Shoreline Permitting Assistance:** *https://glo.texas.gov/coast/coastal-management/permitting/index.html*
- **Texas Living Shoreline Site Suitability Model Online Viewer:** *https://gomaportal.tamucc.edu/GLO/LivingShorelines/*
- **USACE & NOAA SAGE Coast Living Shoreline Brochure:** *http://sagecoast.org/docs/SAGE_LivingShorelineBrochure_Print.pdf*

Living shoreline installation on Galveston Island.