BEACH NOURISHMENT RESILIENCY DESIGN GUIDE

About This Guide

Beach and dune nourishment are nature-based solutions that protect coastal communities and upland infrastructure from impacts due to storm surge and waves. The beach and dunes act as a buffer between upland systems and the water, dissipating wave energy before it can reach vulnerable buildings and infrastructure. These projects also often provide both recreational and environmental benefits. This guide describes key considerations for projects.

Beach Engineering: The Process

Project Feasibility Analysis should take place iteratively throughout the course of project formulation, rather than at a particular step in this process. Issues that will have a material effect on the project may be discovered at any point in this process, and it is important that they be identified as early as possible. Potential issues include:

- Sand availability
- Cost/funding sources
- Project impacts
- Public opinion
- Property ownership
- Permitting requirements

Site Background	Identify stakeholder, funding sources, and project risks; collect data and review previous studies; and characterize the general physical setting of the study area.
Existing & Future Conditions	Develop an understanding of existing conditions and long-term trends, such as relative sea level rise (RSLR), to identify issues and establish project goals.
Beach Design	Develop the project design and success criteria, and evaluate alternatives, extent of nourishment, sand needs (quality and quantity), and renourishment interval.
Dune Design	Understanding Texas dunes, their geomorphology, and the strategies necessary to create, restore, and maintain them.
Sand Sourcing	Identify potential sand sources (short- and long-term), assess sediment compatibility, and evaluate the logistics associated with use of that sand.
Permitting	Coordinate with regulatory agencies to implement a project while avoiding and minimizing project impacts.
Planning & Construction	Assess needs for and limitations of construction, develop Plans and Specs, bid and award the contract, and oversee construction.
Monitoring	Regularly assess beach (and sand source, or borrow) conditions to track project performance, fulfill permit requirements, and guide adaptive management.

Site Background

Prior to project implementation, it is first important to understand the geographic, meteorological, oceanographic, and geologic context of the site. The tides, waves, and winds that prevail throughout the year need to be quantified. A narrative should detail past upland development, shoreline protection measures, and storm impacts.

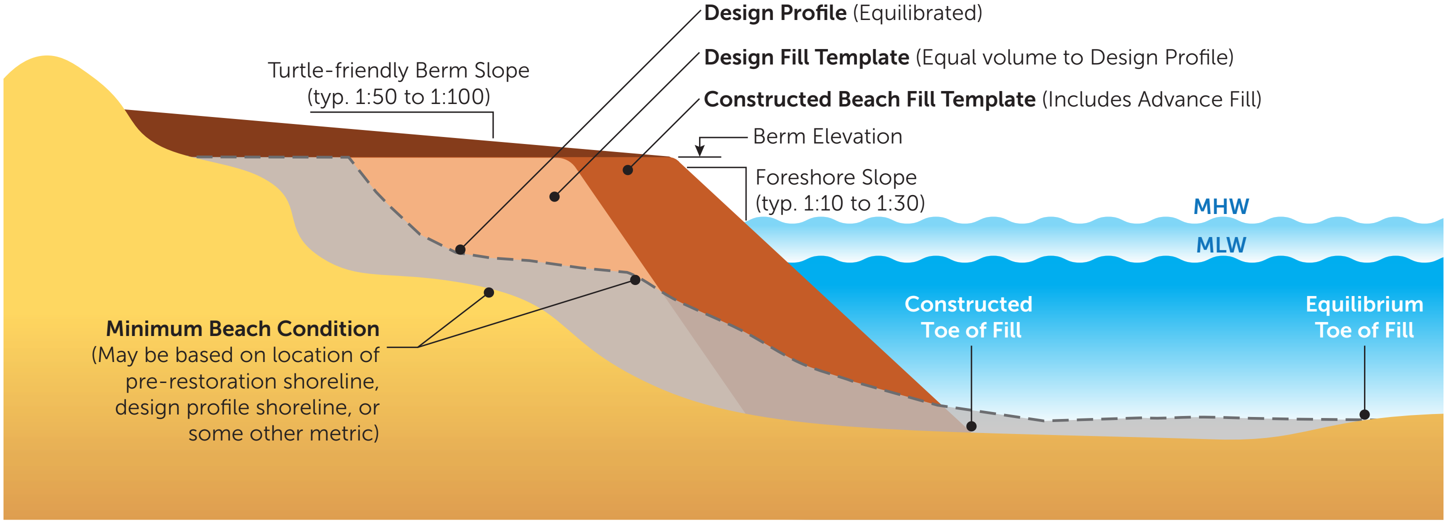
Study area context	Prevailing conditions	Externalities
• Stakeholders • Funding sources • Development history • Land use and land ownership • Past shoreline protection measures • Past storm impacts	• Tides • Waves • Winds • Potential storm impacts • Future sea level projections	Aspects that are partly or wholly outside the control of the project sponsor: • Existing upland and submerged structures (e.g., pipelines) • Public lands and recreational use • Land ownership and encroaching development • Presence of endangered species

Existing & Future Conditions

A detailed understanding of existing and potential future conditions is crucial to developing a scope for and implementing a comprehensive, proactive, and effective beach management program. This should include determining minimum (or critical) beach conditions and typical equilibrium beach configuration, identifying erosion hotspots, and qualifying and quantifying future beach dynamics.

Data sources	Guiding characteristics	Erosion causes	
		Natural	**Manmade**
• Beach survey* • Aerial photography • Orthophotography • Sediment sampling Conditions and concerns: • Erosional/accretional areas • Erosion hotspots • Encroaching development	• Equilibrium beach shape • Minimum beach condition • Background shoreline position and beach volume change rates • Sand spreading analysis and final beach condition	• Storms • Island migration • Shoal migration • Sea level rise • Land subsidence	• Encroachment • Interruption of longshore transport – Inlets, jetties, groins • Recreational use

*The importance of full-length, transect-based beach surveys should not be understated. While Lidar surveys can provide a very detailed representation of beach topographic features, a full understanding of beach dynamics, shoreline change, and sediment transport cannot be achieved without measuring the nearshore and offshore beach. These surveys are ideally collected at least yearly in order to be able to describe the equilibrium condition of the beach, as well as how it responds to various climatic conditions.



Beach Design

Beach design must balance the needs of upland infrastructure protection with those of habitat protection and recreation while maximizing public safety. Key components of beach design are described below.

Berm Elevation is a key design parameter for a beach nourishment project. Healthy beaches generally feature an area of relatively mild slope ("berm") between the toe of dune and an elevation above Mean High Water (MHW). The upper end of this slope is typically used as the design berm elevation, and is generally better characterized by identifying a natural berm elevation than by empirical methods based on the tide and wave climate. In the case of an eroded beach without a notable berm, a slope inflection point at the seaward base of the dune (toe), assuming a non-scarped dune, may give an idea of the design berm elevation. For a severely-eroded (or new construction) beach, empirical methods may be required, though an optimum berm elevation can also be discerned from an iterative process over several renourishment intervals. Alternately, a more sloped berm may allow natural processes to "find" an appropriate berm elevation through equilibration without creating significant scarps or over-inundation of the profile.

The **Berm Slope** has typically been specified as flat for most beach nourishment projects in the past. However, recent analysis has shown that sloping berms (1:50 to 1:100) experience less significant scarping as they erode and equilibrate, making them more "turtle friendly" for sea turtle nesting and safer for the public. Sloped berms also reduce the likelihood of ponding in flat areas landward of the berm edge, where depressions may form as placed sand compacts. With the methods used to grade beach fill, a sloped profile typically does not add any significant complexity (or cost) to a project.

The **Design Profile** is the desired post-construction post-equilibration beach shape and position. Its shape is defined by a Composite Beach Profile, which is a "typical" (average) representation of "natural" (existing) equilibrium beach conditions. A shoreline may be defined by one or more composite profiles, and therefore one or more design profiles, depending on longshore variability.

The **Foreshore Slope** is the beach face slope of the design profile. This slope is generally controlled by construction limitations. It is difficult for earth moving equipment to properly grade sand placed below Mean Low Water (MLW). Sand is typically pushed from the dry beach out into the water to fill the design profile, with the sand basically laying as it falls. While a gentler slope may be preferable for the purposes of equilibration, a steeper slope will be easier to construct. Foreshore slopes typically range from about 1:10 to 1:30, and specifications and permits sometimes allow for moderate alteration of this slope for constructability once the project gets underway.

The **Minimum Condition** is a "critical" or "trigger" condition when action must be taken to prevent the beach from reaching an excessively eroded condition, whereby impacts to upland infrastructure are imminent or storm protection benefits have been reduced to an unacceptable level. Regular post-construction monitoring would enable the project sponsor to identify when this conditions is reached.

Advance Fill is the quantity of sand placed in the design profile beyond that required to achieve the design condition. This quantity may be defined by a seawardmost limit of the equilibrium toe of fill (due to, for example, the presence of hardbottom [reef] resources or some limiting engineered structure) or by an optimal quantity determined as part of a renourishment interval analysis.

Relative Sea Level Rise can generally be well managed within the context of an engineered beach. Due to the natural variability of beaches and their abilities to respond to changing conditions, it is likely that an engineered beach will adapt naturally to some extent to rising seas and changing wave conditions. Additionally, because beaches should receive more frequent maintenance (renourishment) than other engineered structures, there are many more opportunities for intervention as part of adaptive management of the project. As such, while RSLR should be taken into account, it may not be necessary to design to a long-term projection. In fact, because of the dynamic nature of beaches, building a berm too high to account for future RSLR can be just as problematic (resulting, for instance, in a highly-scarped beach face rather than a smoothly equilibrated profile) as building it too low. However, for more permanent structures that are incorporated into a beach management plan, long-term RSLR would certainly be an important design consideration. Relative sea level rise may shorten the lifespan of nourishment projects or result in a more frequent need to renourish.

Renourishment Interval

Renourishment interval is a planning tool

Actual renourishment timeline is often dictated by occurrence of episodic events (e.g., tropical storms, hurricanes), but also includes natural sediment transport.

- Beaches should be managed, to the extent possible, as fairly stable and resilient features
- Highly erosive ("hotspot") areas may be best treated by means other than frequent placement of renourishment sand
  - In some cases, sand placement may not be sufficient and engineered structures need to be used in concert
  - Implementing policy to "naturalize" shoreline could include:
    - » Improving inlet sediment management, including retention, bypassing, and back-passing
    - » Removing infrastructure that protrudes onto the beach
    - » Decommissioning non-functioning or negatively functioning existing shoreline stabilization measures

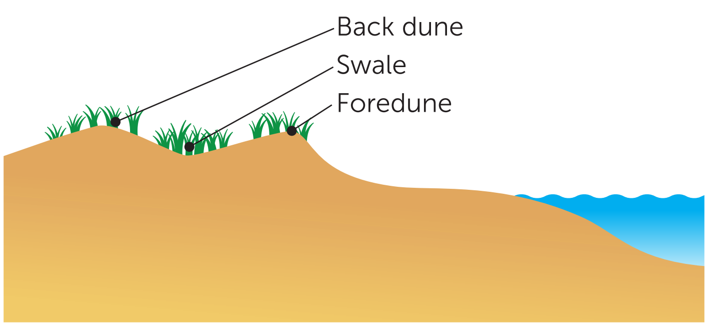
Renourishment interval planning is a balancing act!

Shorter (3-5 years)		Longer (8-10+ years)	
Less sand per placement		**More sand per placement**	
• Lower total cost per placement	+	• Higher total cost per placement	−
• Higher cost per cy	−	• Lower cost per cy	+
Less advance fill		**More advance fill**	
• Less protection against catastrophic erosion events	−	• More protection against catastrophic erosion events	+
• Less impact to offshore resources	+	• More impact to offshore resources	−
More frequent disruptions to environmental resources, public use	−	*Less frequent disruptions to environmental resources, public use*	+

Coastal Dune Design and Restoration

A well developed, protected dune system provides a resilient natural barrier to wind and waves, making it a cost-effective defense against the impacts of storm-surge flooding and erosion.

Dune/Beach System



Characterization of Texas Coastal Dunes

Dune systems are comprised of a foredune and back dunes, with the possibility of a foredune ridge.

- **Foredune** - first vegetated dune closest to the coastline that absorbs the initial brunt of storm surge and dissipates wave energy
- **Back dune** - most landward dune before the dune system transitions to vegetated flats or prairies
- **Swale** – low-lying depression between dune crests that is typically characterized by wetland vegetation

Texas dunes provide a natural buffer to storms, sustain an array of diverse flora and fauna, and provide an aesthetic view to beach goers and coastal residents.

Dune Damage

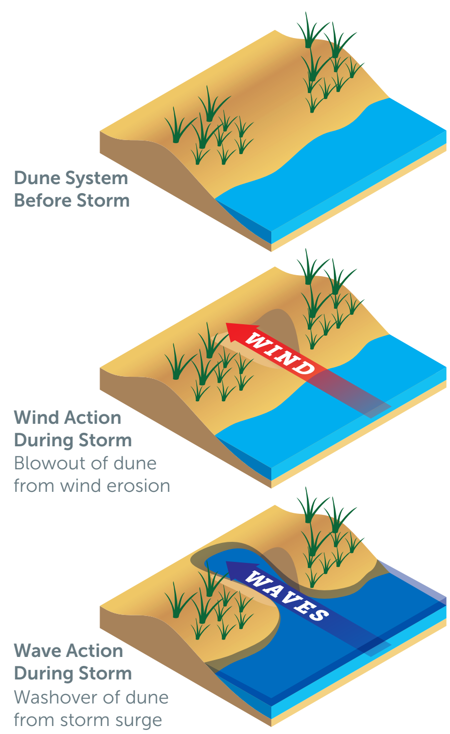
Sand dune formation occurs as a natural effect of wind and wave driven sand. During the calmer summer season, waves along the Texas coast are small, which allows them to carry sand from offshore sand bars and deposit it on beaches. As the sand is blown or pushed landward, it gets trapped in foredune vegetation.

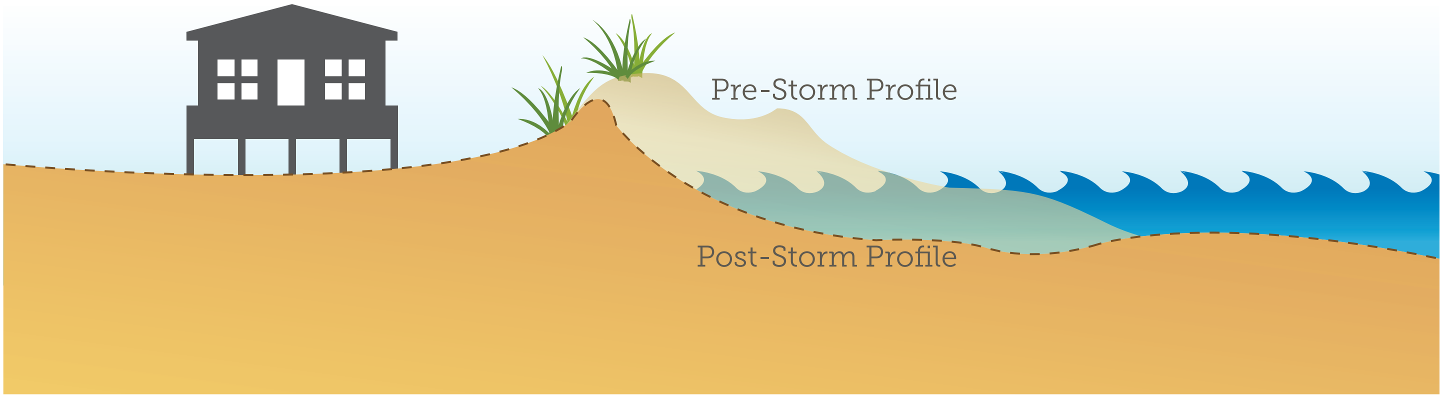
Blowouts are breaches in the dunes caused by wind erosion. They are usually aligned with prevailing southeasterly winds and are often cut down to the water table. During storms, blowouts may become channels for storm surge from the Gulf, leading to washovers and washouts.

Washovers occur if the height of approaching waves or storm surge exceed the height of depressions along the dune ridge. When that occurs, water may start to overflow the low points and wash down the landward side of the dunes, eroding sand and carrying it inland. Under continuous wave impact, these areas begin to widen and deepen, allowing larger volumes of water to go inland.

High-water events may also produce **washouts** in dune systems, where water flows seaward. If there are breaches or depressions in the dunes, the rainwater that accumulates in the swales may channel through the low points and overflow onto the beach. Hurricanes may pile water into bay systems and, if the natural channels to the Gulf are too narrow to accommodate water retreating from the bays, washouts may cut across the areas of least resistance.

Following a storm, the natural beach/dune system can recover its pre-storm shape if enough sediment is available in the littoral system. In Texas, this process can take up to five years, first by beach accretion, then by dune formation, expansion, and vegetation colonization.





Design and Restoration

Dune vegetation projects in Texas can use three main, appropriate species of grass: bitter panicum (*Panicum amarum*), sea oats (*Uniola paniculate*), and marshhay cordgrass (*Spartina patens*). These are not always available commercially and often have to be transplanted from natural stands.

- **Bitter panicum** is the best species for dune stabilization on the Texas coast. This native beach plant has a higher salt tolerance than other coastal species and is a hardy grower (plant early winter to early summer).
- **Sea oats** may be interspersed among bitter panicum to reduce the risk of disease or pest infestation. Harvest only healthy, vigorous plants for transplanting (plant mid-winter to early spring).
- **Marshhay cordgrass** does well on the landward side of dunes; if planted on the beach side, the grass is easily buried and destroyed by shifting sands. The most appropriate use for marshhay cordgrass is to repair the more stable portions of existing and new dunes (plant late winter through early spring).

Transplants from the vicinity of the project are more likely to survive than imported plants. If harvesting or planting occurs on a Gulf-facing beach seaward of a dune protection line, a permit from a county commissioners court or city may be required. A transplant survival rate of 50 to 80 percent can be expected; if the survival rate is less than 10 percent, the area should be replanted. The vegetation should be dense within one or two years; any bare areas that remain after that time can be replanted with vegetation from the well-established sites.

For planting, small areas and steep slopes at the site are best vegetated by hand.

- Generally speaking, a planting density of every 2 square feet is recommended.
- Transplanted vegetation needs little maintenance.
- Continual watering of the newly planted vegetation, especially during drought conditions, is encouraged to help increase the likelihood of survival.

Damage to dunes from pedestrian traffic can be avoided using elevated walkovers for beach access. If walkovers are placed near access roads, parking areas, and public facilities, pedestrians will be less likely to cut footpaths through the dunes. A walkover should begin landward of the foredune and extend no farther seaward than the most landward point of the public beach, where it will not interfere with public use of the beach at normal high tide. The structure should be oriented at an angle to the prevailing wind direction.

Sand fencing is used to help trap sand and stabilize dunes, but it should be considered temporary stabilization and removed when vegetation is established, become at least 50% buried by sand, or are damaged or no longer functioning. These structures can be made of slatted wood, porous netting, or organic debris.

- Standard **slatted wood** sand fencing is inexpensive, readily available, easy to handle, and can be erected quickly.
- **Organic debris**, such as Christmas trees, brush, and seaweed can also be effective for trapping sand. Make sure that the piles are not too dense, and that air can flow within them.
- **Non-structural, inorganic debris**, such as automobile bodies, concrete, wire, or tires, should not be used for dune building. These materials are not biodegradable and are safety hazards.

A height of three feet after installation (measured from the ground surface) is recommended for dune-building structures. In areas where sand conditions are poor for dune building, a height of two feet is appropriate. The fencing can then be supported with wooden posts driven at 10-foot intervals. Sand fencing should be placed in non-continuous, diagonal segments—at least 35 degrees to the shoreline—so as not to adversely affect sea turtle nesting areas.

Reinforced dune projects combine various materials with sand and vegetation, mimicking the appearance and function of natural dunes. These are dunes designed and built as hybrid structures using materials such as geotextiles, hay bales, sheet pile, rip rap, gabions, or clay to reinforce the dune core. In many cases on Gulf-facing beaches, dunes constructed with hard cores are considered hard shoreline armoring and are restricted by additional regulations, and must abide by 31 TAC § 501.26.

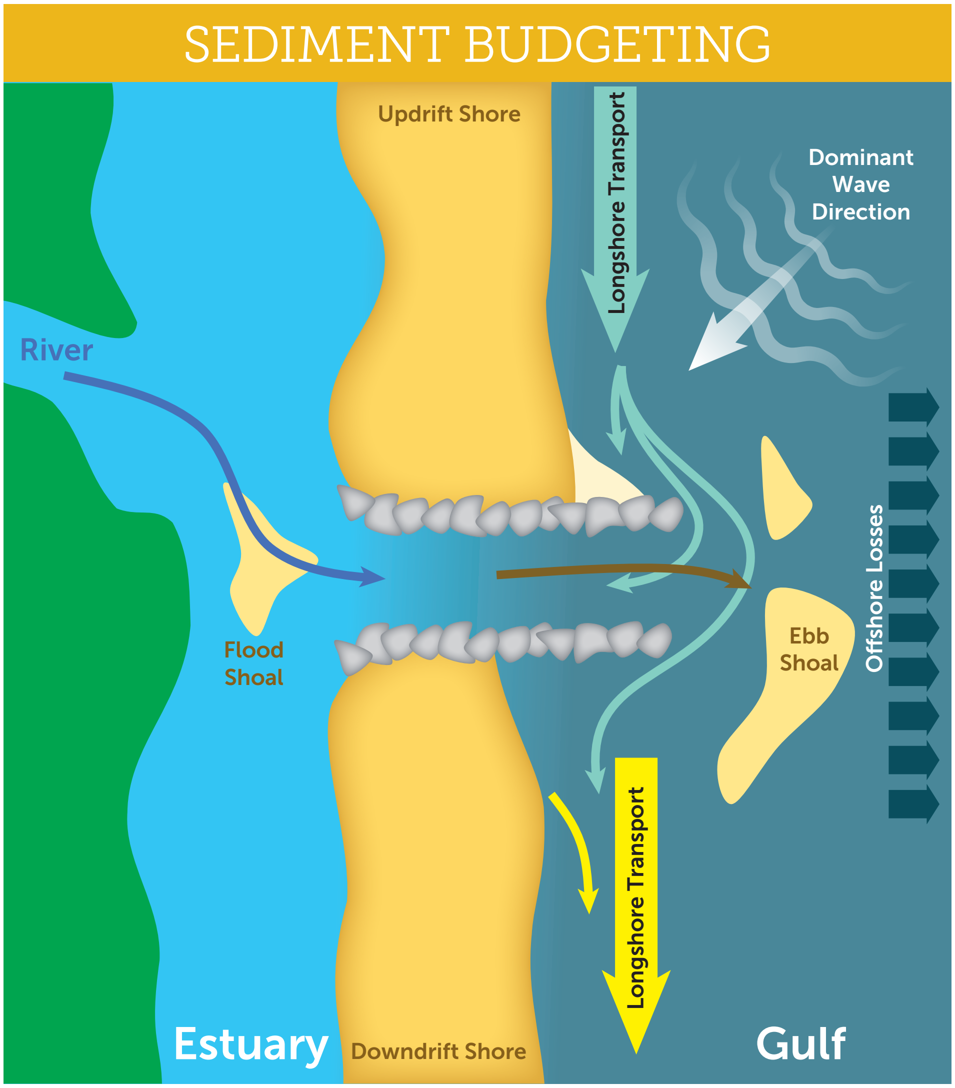
Human Impact

Human activities can take a damaging toll on dunes. Disturbance of the foredunes by vehicles, pedestrians, or construction work can exacerbate erosion. As trails are established along frequently used routes through the dunes, the vegetation is destroyed, and wind begins to carry sand from the exposed area. As a greater area is exposed to erosion, a blowout, washout, or washover may develop. If left unchecked, this can lead to almost complete removal of dunes, depleting the supply of sand available for absorbing wind and wave energy during storms.

Drainage features resulting from construction must not erode dunes, the public beach, or adjacent properties. GLO rules require that new channels be directed inland instead of through critical dunes toward the gulf. Damage to dunes and to property behind them can be prevented or halted by installing a retention pond. The pond should be large enough to contain the anticipated volume of runoff and located where it will receive the maximum amount of drainage. A qualified professional should design the system and oversee its construction.

Sand Sourcing

Both short-term and long-term project sand needs must be quantified in order to identify potential sand sources. The quality, quantity in cubic yards (cy), and sustainability of those sources, as well as any competing claims on their use, must be understood in order to plan for the long-term success of a beach management plan.



Ocean or offshore

- Several dredge types that must be ocean certified
- Clean fill from navigational dredging
- 10,000 to 50,000+ cy/day
  - Dependent on dredge size, borrow configuration, and weather
- $8 to $15+/cy
  - Higher with restricted borrow area, or long distance to borrow
- $1,000,000+ mobilization for large dredge

Inlet or inland waterway

- Range of dredge sizes, types
- 3,000 to 50,000+ cy/day
  - Highly dependent on dredge size and borrow location
- $6 to $15+/cy
- $100,000+ mobilization for small dredge

Upland sand

- Truck haul, typically
- 1,000 to 3,000+ cy/day
  - Highly dependent on logistics (number of trucks, accesses, routes, staging areas)
- $30+/cy
  - Depends on distance to sand source and various logistics

Construction and maintenance costs can be estimated at $1.1 million per mile of beach.[2]

Whatever the source, a detailed sediment compatibility analysis will need to be conducted. This will examine how well the proposed placement sand matches the geotechnical characteristics (grain size distribution, color, fines/shell/carbonate content) of the existing.

Permitting

While project design will determine permitting needs, the permitting process should also inform the project design. The permitting process should be started as early as possible by setting up a Pre-Application meeting with all stakeholders and regulatory agencies to discuss project feasibility and get an early idea of issues that may need to be addressed.

Agencies and their Jurisdictions	Potential Requirements
• **U.S. Army Corps of Engineers (USACE):** Potential damage to aquatic environment or U.S.0 waters under Section 404 of the Clean Water Act • **Texas General Land Office (GLO):** Coastal Boundary Survey, Surface Lease Agreement, Coastal Zone Management Consistency Certification, and compliance with Dune Protection Act and Open Beaches Act and local government Beach Access and Dune Protection Plans. • **U.S. Fish and Wildlife and National Marine Fisheries Services:** Potential impacts to ("take" of) federally-protected species under Section 7 of the Endangered Species Act (ESA) • **Texas Historical Commission:** Impacts to cultural marine resources under Section 106 of the National Historic Preservation Act	• Avoidance and minimization of take, impacts to habitats, etc. • Lighting restrictions • Safety measures during construction due to certain nesting birds and turtles, including the need for a Protected Species Observer • Response planning in the event of take • Mitigation for take and impacts to dunes • Various post-construction monitoring (see "Monitoring")

USACE Links: *https://www.swg.usace.army.mil/Business-With-Us/Regulatory/Permits/Permit-Application*
GLO Links: *https://glo.texas.gov/coast/coastal-management/permitting/index.html*

Planning & Construction

Before construction gets underway, there are still several important tasks that must be completed, including developing the engineering plans and specifications and bidding out the construction work.

Planning for Construction	Plans & Specs	Bidding and Awarding	Construction Oversight
• Construction windows • Nesting/migration windows • Permit requirements • Weather • Tourism • Logistics • Phasing/sequencing • Equipment storage • Construction access • Public outreach • Quality control (QC)	• Adding detail – consider Contractor's needs • Laying out construction windows, restrictions, and requirements clearly • Planning for surveying and contractor BD/AD ("before dredge, after dredge") surveys	• Estimating probable cost • Advertising and distributing bid packages • Pre-bid meeting • Respond to questions/comments • Adapting plans & specifications • Reviewing bids for completeness and qualifications • Comparing bids and awarding	• Visual QC • Pay survey QC • Adapting the design in the field • Answering contractor questions • Implementing ESA and other monitoring during construction, as required by permit

Monitoring

Determine what surveys will be required to assess project performance and adapt/improve a beach management plan.

Physical	Environmental & Biological

Beach Transect Survey
• Required both pre- and post-placement and after a roughly 6-month equilibration period, then once annually, or as required by permit
• Additional surveys (possibly targeted) immediately following erosion events are highly recommended to document losses
• Consistent longshore spacing (i.e., 1,000 to 3,000 feet)
• Cross-shore from landward of dune field to offshore of estimated "depth of closure"
Aerial Photography
• Ideally coincident with one or more of the transect surveys
Borrow Area Hydrographic Survey
• Yearly or twice yearly to track recovery of dredged area for potential future re-use or to measure water quality (and/or to fulfill permit)
	Placed Sediment Testing
	• Geotechnical characteristics likely required by permit immediately post-construction
	• Biological characteristics may be required by permit until recovery of benthic invertebrates/beach microbiome to pre-construction baseline
	Beach Scarp Check
	• Identifying and grading (flattening) any beach scarping alongshore
	  – Immediately prior to turtle nesting season to limit false crawls
	  – Throughout the year (except nesting season) for recreational safety
	Possible Additional Considerations
	• Borrow area sediment testing could be used to confirm recovery of benthic species to pre-construction baseline or to check geotechnical characteristics of infill material to assess potential future re-use of borrow area
	• Beach hardness testing or post-construction beach tilling could be conducted in first turtle nesting season after placement to improve nesting results

Beach Management Techniques

Structural alternatives should be used sparingly

1. Every implementation should be site specific. There is no one-size-fits-all prescription for beach management!
2. Structures do not create sand, but they can help manage it as part of a comprehensive sand management plan.
3. Structures typically introduce some adverse effect to adjacent shorelines when used on the open coast.
4. Structures are most effective in discrete littoral cells (pocket beaches anchored by t-head groins) or at the terminal ends of long beach systems.
5. Structures perform best when their construction is accompanied by sand placement.
6. If structures already exist at the study area, there could be a unique opportunity to use a nature-based solution design that takes advantage of the existing infrastructure.
7. Performance characteristics below may be improved by combination of techniques.

*Green and gray structural techniques to manage Gulf and bay shorelines**

"Green" (Softer) Techniques ↑ / "Gray" (Harder) Techniques ↓

Technique	Permanence	Cost	Adaptability to RSLR	Wave Energy Reduction	Benefits and Drawbacks
Dune Planting**	mod	low	high	low	**Benefits:** stabilizes dune, captures wind-blown sand, assists in additional plant colonization, improves dune habitat
Sand Fencing	low	low	N/A	N/A	**Benefits:** captures wind-blown sand, assists in plant colonization, small footprint, unobtrusive **Drawbacks:** requires periodic adjustment for maximum effect; may become a safety or debris concern once deteriorated
Dune Nourishment	mod	mod	mod	mod	**Benefits:** supplies sand to berm, provides dune habitat, absorbs wind and wave energy from storms **Drawbacks:** disruption to beach microbiome, temporary disruption to beach recreation during construction
Inlet Sand Bypassing	low	high	mod	N/A	**Benefits:** offsets sand transport disruption effects of inlets and jetties **Drawbacks:** requires permanent dredge installation or frequent dredge mobilization, disruption to beach recreation during bypassing activities
Beach Nourishment	low	high	high	high	**Benefits:** provides recreational opportunities; able to adapt to wave climate and recover from losses **Drawbacks:** dredging may increase water turbidity; causes disruption to beach microbiome, turtle nesting, and beach recreation during construction
Engineered Reef	mod	mod	low	mod	**Benefits:** provides marine habitat, recreation opportunities
Breakwater	high	high	mod	mod	**Benefits:** salient/tombolo creation, creates sheltered recreation/marina areas **Drawbacks:** downdrift & updrift erosion, disruption to turtle nesting, disruption to beach recreation during construction
Revetment***	high	high	low	mod	**Benefits:** anchors shoreline location, prevents upland erosion **Drawbacks:** profile deflation, downdrift erosion, vulnerable to flanking, vulnerable to destabilization from overwash, disruption to turtle nesting, disruption to beach recreation during construction, difficult to permit
Groin***	high	high	low	low	**Benefits:** updrift accumulation **Drawbacks:** downdrift erosion, vulnerable to flanking, disruption to beach recreation during construction
Jetty***	high	high	mod	low	**Benefits:** updrift accumulation, anchors inlet location **Drawbacks:** downdrift erosion, vulnerable to flanking, disruption to beach recreation during construction
Seawall***	high	high	low	mod	**Benefits:** anchors shoreline location, prevents upland erosion, small footprint **Drawbacks:** profile deflation, downdrift & updrift erosion, vulnerable to flanking, vulnerable to destabilization from overwash, disruption to turtle nesting, disruption to beach recreation during construction, disrupts aesthetics, cuts off upland habitat from beach

**Requirements vary for Gulf and bay shorelines. For Gulf facing applications, see 31 Texas Admin. Code § 15 and § 501.26*
***Requires sourcing of appropriate native plants based on NRCS service areas. For more information visit the NRCS information page*
****Can only be constructed with extensive permitting requirements in order to protect public infrastructure*

Additional Information and Resources

1. USACE Natural Infrastructure Opportunities Tool: https://ewn.el.erdc.dren.mil/tools.html
2. GLO Dune Protection and Improvement Manual for the Texas Gulf Coast: https://www.glo.texas.gov/coast/coastal-management/forms/files/dune-protection-manual-gpb.pdf
3. Galveston Park Board - Galveston Island Sand Dunes Maintenance Manual: https://www.galvestonparkboard.org/DocumentCenter/View/46/Park-Board-Dune-Maintenance-Manual-PDF
4. USDA Plants for Coastal Dunes of the Gulf and South Atlantic Coasts and Puerto Rico: https://naldc.nal.usda.gov/download/CAT10416856/PDF
5. Field Performance of Reinforced Dunes for Improving Coastal Resiliency: https://ascelibrary.org/doi/abs/10.1061/9780784482155.006
6. NOAA Nature-Based Solutions Installation and Maintenance Costs: https://coast.noaa.gov/data/digitalcoast/pdf/nature-based-solutions-installation-maintenance.pdf