Improving Coastal Community Resilience to Sea Level Rise
with Natural Infrastructure

NETWORK FOR ENGINEERING WITH NATURE

UNIVERSITY OF GEORGIA

Institute for Resilient Infrastructure Systems
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Created by the University of Georgia Institute for Resilient Infrastructure Systems, University of Georgia Marine Extension and Georgia Sea Grant, and the Network for Engineering with Nature, this publication is designed serve as a resource for local government, coastal landowners, members of the public, and natural resource management agencies interested in learning about the role of natural infrastructure in coastal resilience.

This publication is dedicated to Tim Welp, a research hydraulic engineer with the U.S. Army Engineer Research and Development Center, who was a leader in the dredging industry and provided technical support to numerous natural infrastructure projects conducted by the U.S. Army Corps of Engineers. Tim passed away during the production of this publication and his contributions to it and to advancing natural infrastructure projects around the U.S. had profound impacts that will be missed by his colleagues and friends.

Introduction

Many coastal communities on the Atlantic and Gulf Coasts, along with their infrastructure (e.g., roads bridges, pipelines, buildings, etc.) are threatened by sea level rise and the associated increases in flooding, storm surge, beach erosion and tidal channel migration ***(Figure 1)***. Society must find ways to increase community resilience to these threats. Adapting to sea level rise and climate change will require exploring nature-based solutions, retrofitting traditional infrastructure and evolving policy programs.

> ***Nature-based or natural infrastructure solutions enhance the functions of naturally occurring landscape features that provide valuable services to people and society, such as minimizing damages from floods and shoreline erosion.***

Some examples of natural infrastructure that mimic natural processes include salt marshes, oyster reefs, sand dunes and living shorelines. These features can be protected, enhanced, constructed, or reconstructed to increase the resilience of coastal communities to sea level rise and climate change.

The functionality of natural infrastructure is dynamic, changing over time, and can be impacted by storms. During Hurricane Ian in 2022, dunes, barrier islands, and marshes reduced the wave energy associated with storm surge and reduced damages in many places. Natural infrastructure also provides co-benefits such as wildlife habitat, recreational opportunities and beauty. Like all infrastructure, nature-based solutions and natural infrastructure must be monitored and maintained over time as sea level rise, tides and storm surges continue.

Atlantic and Gulf Coast Vulnerabilities

The Atlantic and Gulf coasts are naturally dynamic environments. From Long Island all the way to the mouth of the Rio Grande in Texas, the coastline consists of low-elevation barrier islands with dunes and sandy beaches facing the sea and surf. These islands are divided by tidal channels or rivers, and they back up to salt marshes and tidal creeks that separate them from the mainland ***(Figure 1)***. Many properties on these islands are low-lying, often less than 6 feet above the normal high-water mark, although the dunes between these homes and the sea can be much higher.

Figure 1. *Highly developed barrier island of Tybee Island, GA, showing shoreline changes since 1863. USGS Coastal Change Hazards Portal.*

The management of coastal infrastructure is complicated by fixed property boundaries, which are not respected by the natural, geologic processes that shape barrier islands. Over hundreds and thousands of years, barrier islands have changed due to fluctuations in sediment delivery by rivers and losses of sediment from wave energy, longshore currents and wind erosion. Ongoing sea level rise tends to push barrier islands, estuaries and their associated wetlands landward. An examination of the topography of the coast and the continental shelf reveals evidence of repeated landward and seaward migrations of the shoreline as ocean levels fell during continental glaciation periods and rose during interglacial periods. Analysis of historical maps from the last 200 years reveals shoreline movement of up to several hundred yards due simply to the dynamics of sediment deposition and erosion ***(Figure 1)***. Hurricanes frequently make landfall on the southeast coast ***(Figure 2)***, and hurricane-driven storms overwash sections of these islands every few decades.

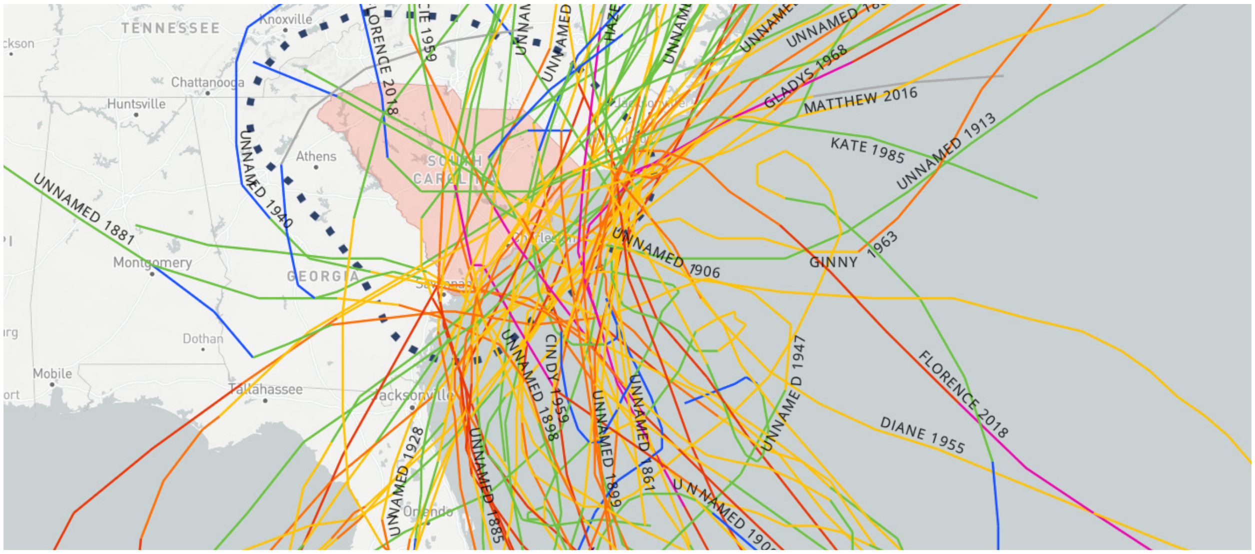


Figure 2. *Historical tracks of hurricanes that have made landfall in South Carolina. From NOAA Hurricane Tracks.*

In many locations, adaptation to sea level rise is constrained by historical building patterns. Due to the aesthetic and recreational allure of coastal areas, barrier islands and mainland-connected beaches have been heavily developed. Exceptions are areas where the land is protected as parkland or placed into long term conservation easements. Coastal development increases the economic costs associated with flooding and storm damage. Barrier islands are covered by houses, hotels, condos, commercial buildings, docks and boat launches that are connected by roads, causeways, bridges, water and sewer lines, natural gas lines and power lines. All coastal states now have rules preventing development on dunes, and the Clean Water Act protects against marsh filling, but, in many places, development occurred before dune and marsh protection laws were established. There are several coastal areas where decades of beach erosion have eliminated dunes and tidal channel migration has eliminated the marsh that separated buildings from beaches and channels (***Figure 3***).

Figure 3. *Beach-adjacent houses partly protected by beach nourishment and partial dune restoration on a South Carolina barrier island. Offshore sand was dredged and sluiced to the beach to replace sand lost to long-term erosion.*

Sea Level Rise and Flooding

Sea levels in the southeastern U.S. have risen approximately 0.7 feet over the last 100 years due to thermal expansion of the ocean and partial melt of the Greenland Ice Sheet and glaciers. They are expected to rise approximately three feet over the next century, with estimates ranging from two to nine feet, according to the NASA Sea Level Change Team's Sea Level Rise Tool. Sea level rise is drowning marshes, accelerating marsh and beach erosion and increasing the frequency and severity of flooding in coastal communities. As sea level rise continues, lower portions of coastal communities will become inundated during normal daily tidal cycles ***(Figures 4 and 5)***. These tidal floods can close roads, isolate communities, introduce seawater into sewage conveyance systems, prevent the drainage of rainfall during storms and require elevation of structures.

Sea level rise also raises the base level of water prior to storm surges from tropical storms, further increasing flood damages. When a hurricane makes landfall on the Gulf or Atlantic Coast, the onshore winds to the north or west of the eye push ocean water onshore, creating what is known as storm surge. Storm surge, and the wave energy associated with it, are responsible for much of the property damage during landfall. Storm surge and wave energy can be reduced by dunes, wide and flat beaches, reefs or breakwaters placed parallel to the shoreline, and marshes. Barrier islands partially protect the mainland by reducing the energy of storm surges.

Sea level rise will require a set of adaptations such as enhancing natural infrastructure, managed retreat, and making extensive alterations to existing infrastructure, including elevating roadways, utilities and structures.

Figure 4. *High tide flooding on U.S. 80, Chatham County, GA.*

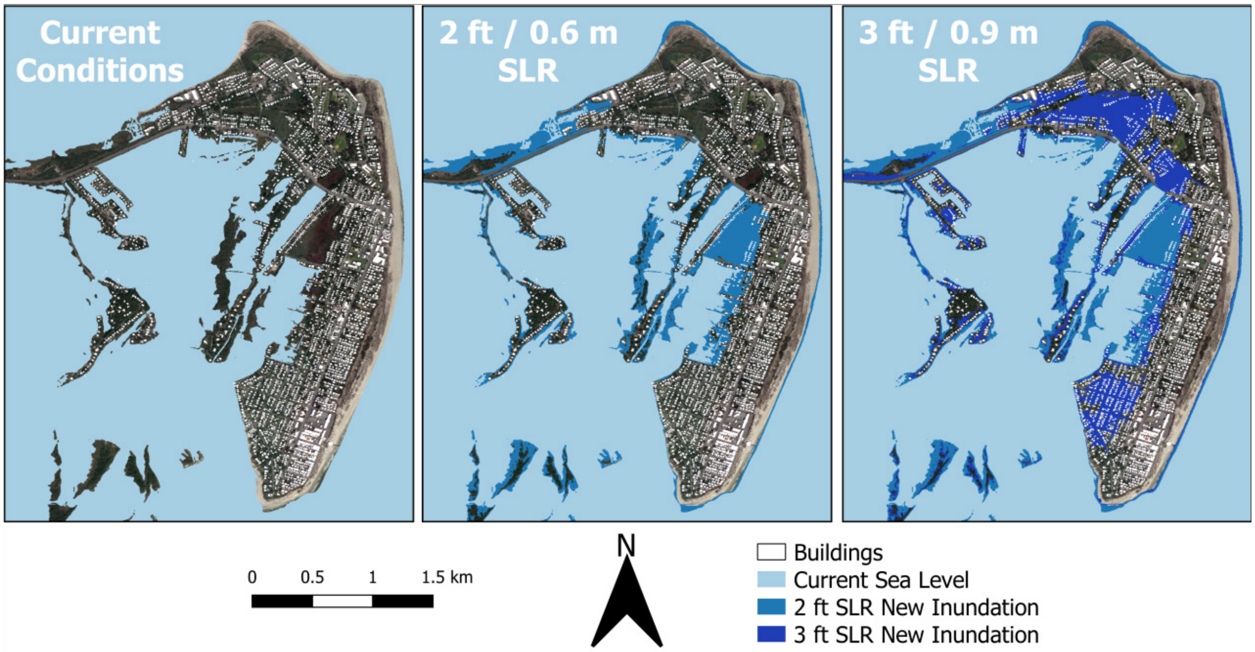
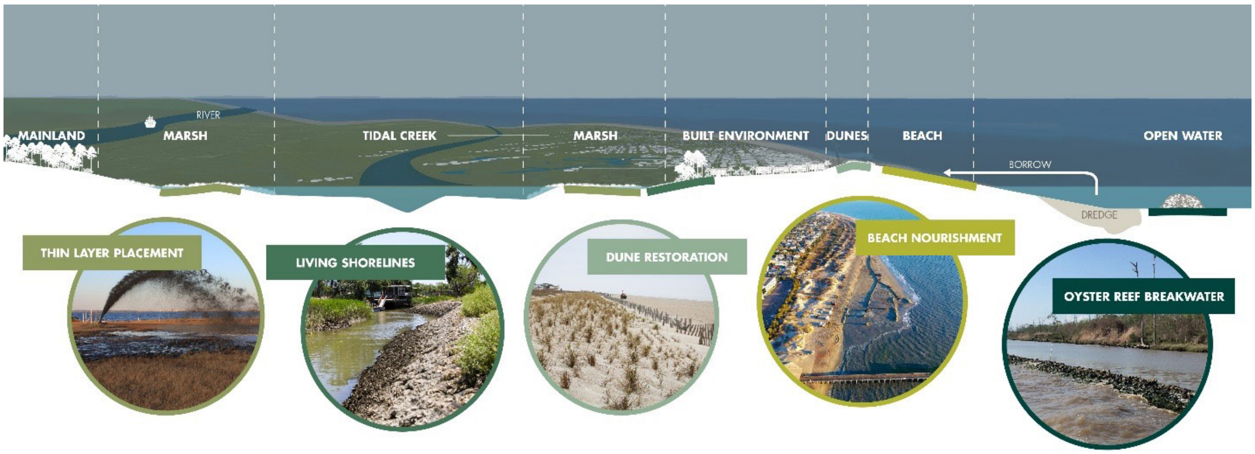


Figure 5*. Tybee Island, GA, present condition and inundation after 2 and 3 feet of sea level rise. Sea level rise projections from the NOAA Sea Level Rise Viewer (NOAA, 2016). Building footprints from the Savannah Area Geographic Information System (SAGIS: https://www.sagis.org/). Tybee Island is rated "Very High" for Coastal Vulnerability on the USGS Coastal Change Hazards Portal.*

Natural Infrastructure Solutions

Preserving, nourishing, and enhancing natural infrastructure as well as coupling natural infrastructure with traditional infrastructure, is critical to improving the resilience of coastal communities to tropical storms, floods and shoreline erosion. Sand dunes diminish the height and energy of waves during storm surge events while also providing nesting habitat for turtles and an aesthetic amenity for people. Marshes diminish storm surge affecting the mainland and backside of barrier islands. They also provide the bulk of primary productivity in estuarine ecosystems and offer recreational opportunities for people. Barrier islands serve as natural infrastructure to diminish and deflect storm surge impacts on the mainland. Natural infrastructure can be preserved, restored, or coupled with traditional engineering structures to increase the resilience of coastal communities to the effects of sea level rise, tidal flooding, and tropical storms while also improving the quality of life for residents and visitors ***(Figure 6)***.

The following section will highlight several natural infrastructure solutions that may be appropriate for the Atlantic and Gulf Coasts. Some of these solutions require sediment, including beach nourishment, dune restoration and thin layer placement. The process of dredging harbors and the intracoastal waterway creates a continual supply of sediment. Every harbor for cargo ships conducts dredging to keep channels navigable. Beneficial use is the repurposing of dredged materials to enhance natural infrastructure or wildlife habitat. Where logistically feasible, beneficial use of dredge materials can lower the economic and environmental costs of natural infrastructure projects and of dredging. In some cases, dredging of offshore sands can be used to supply beneficial use projects. Understanding the natural inventories and transport of coastal sediments is part of beneficial use planning and coastal sea level rise adaptation.



Graphic developed by Rhett Jackson and Kelsey Broich, Network for Engineering with Nature, University of Georgia. Thin layer placement image by Tim Welp, USACE. Living shoreline and dune restoration images by UGA Marine Extension and Georgia Sea Grant. Beach nourishment image by Alan Robertson, City of Tybee. Oyster Reef Breakwater, Bon Secour National Wildlife Refuge in Alabama photo used with permission and provided to the University of Georgia by USACE, Engineering With Nature.

Figure 6. *Examples of engineered natural infrastructure applied to the barrier island environment to help increase the resilience of these communities to sea level rise and tropical storms. The design and location of these solutions is guided by state and federal regulations that inform the placement and use of certain materials.*

Beach Nourishment

Figure 7. *Spreading dredged sediments in a beach restoration project. Courtesy of USACE ERDC.*

Wide, sandy beaches provide recreational and economic benefits to visitors while also providing coastal storm protection and ecosystem services. Water damage to upland areas can be eliminated or reduced because wave energy is absorbed, and surge and tide elevations lessened. To provide sufficient protection, the beach must have sufficient width and height. Beach nourishment involves adding sediment to beaches that are experiencing increasing erosion rates due to sea level rise, or other coastal processes in order to maintain a desired level of protection ***(Figure 7).*** The design of a beach nourishment project is based on several factors, including site characteristics of the specific location as well as the quantity, time and cost of the sediment that is needed. Additional factors to consider include ecological, social and economic impacts of the project.

Dune Restoration

Dunes provide important habitat and create the beloved, iconic look of a Coastal Plain beach. Intact and vegetated sand dunes also play a role in reducing the power and extent of storm surge and wind energy when tropical storms come ashore. Communities behind dunes suffer less damage in tropical storm conditions than communities on beaches without dunes. In some locations, dunes have been eliminated due to development, and, in others, they have eroded away.

Dune restoration involves the placement and shaping of sands and planting native dune vegetation (Figure 3).

When coupled with beach nourishment, dune restoration increases the resilience of coastal communities to tropical storms and extreme high tides resulting in high tide flooding events. A contiguous dune system with elevated beach access points prevents storm surge from funneling through gaps. The dominant costs associated with dune restoration is moving and placing sands from offshore or rivers, and maintaining and replacing dunes in the event of future erosion.

Thin Layer Placement

Figure 8. *Thin-layer placement of dredged sediments to raise marsh elevations. Courtesy of USACE ERDC.*

Unlike the other tools highlighted in this document, thin layer placement is a technique that can be applied to any number of coastal habitats, including beaches, wetlands and subtidal mudflats. It is a practice designed to restore or maintain flood risk management and ecological function through the placement of sediment on these habitats ***(Figure 8).***

The U.S. Army Corps of Engineers *(Berkowitz et al., 2019)* defines **thin layer placement** as “purposeful placement of thin layers of sediment (e.g., dredged material) in an environmentally acceptable manner to achieve a target elevation or thickness. Thin layer placement projects may include efforts to support infrastructure and/or create, maintain, enhance, or restore ecological function.”

Breakwaters, Sills and Oyster Reefs

In some cases, hardened structures can be used to mitigate shoreline change. These structures may be composed of natural or artificial materials and are designed to alter the effects of wave energy and slow coastal erosion, while improving natural habitats.

A **breakwater** is a shore-parallel structure that "breaks" waves, reducing the wave energy reaching the beach and fostering sediment accretion between the beach and the breakwater.

Made of rock, concrete, or oyster shell, the design of these structures varies based on site conditions. They can be floating or fixed on the ocean floor. They can also be continuous or segmented. Breakwaters can be placed attached to the shoreline or submerged near the shoreline as sills. Breakwaters allow for the accretion of sediment between the structure and the shoreline, potentially stabilizing wetlands and providing shelter for new intertidal marsh habitat.

Figure 9*. Restored oyster reef. Courtesy of University of Georgia Marine Extension and Georgia Sea Grant.*

Oyster reefs form natural breakwaters, reducing shoreline erosion by dissipating some of the wave energy associated with incoming tides and storm surges. Community-based restoration projects have created new reefs for the dual purpose of ecological enhancement and shoreline protection. They can be used to create breakwaters or sills. They can also be incorporated into other natural infrastructure projects such as living shorelines. Oyster reefs are usually established by collecting oyster shells or other hard substrate and placing it in the water (Figure 9). The effectiveness of creating new reefs depends on a variety of factors that include temperature, oyster growth and survival, as well as the height and width of the reef.

Oysters play a critical role in maintaining a healthy coastal ecosystem. Dense populations of oysters can significantly improve water clarity and quality by filtering algae and pollutants. Oyster reefs also provide a hard substrate in the otherwise soft, muddy bottoms of estuaries for oyster larvae and other organisms to settle, attach and grow. Intertidal reefs provide spawning, breeding, feeding and nursery habitat for many commercial and recreational species that are ecologically and economically important to the region.

Living Shorelines

Figure 10. Living shoreline at the Burton 4-H Center on Tybee Island, GA. Courtesy of University of Georgia Marine Extension and Georgia Sea Grant.

Traditional shoreline protection uses seawalls and bulkheads that harden the shore and cause a break between the marsh and upland ***(Figure 10)***. These structures offer protection across the design-life of the structure but require periodic maintenance and will eventually need to be replaced.

Tides are constantly changing, and a living shoreline works with the natural environment by maintaining a connection between the marsh and upland area. This enhances habitat, allows for natural marsh migration and protects properties from erosion.

> **Living shorelines** are an approach to estuarine shoreline stabilization that use natural materials, like oysters or native plants, to protect shorelines from erosion. They provide an alternative to traditional armoring techniques that use hardened structures like bulkheads or revetments.

Living shorelines can stand alone, or, in some states, they can be integrated into a bulkhead as a hybrid solution. Their design should mimic a reference community composed of oysters, which thrive at the lowest section near the toe of the shoreline and extend upward to the mean sea level. Depending on your geographic location, ribbed mussels *(Geukensia demissa)*, which also help to hold sediment in place, may be found in conjunction with smooth cordgrass *(Spartina alterniflora)*.

Coastal Resilience Law and Policy

Improving coastal community resilience using natural approaches requires a variety of policies spanning scales, jurisdiction, and expertise ***(Figure 11)***. Both regulations and incentives will be necessary to mitigate the costs and challenges of sea level rise and coastal dynamics. Increasing the use of natural infrastructure also requires policy innovation and novel approaches to shoreline management. Successfully incorporating natural infrastructure into coastal management practices requires a comprehensive understanding of existing legal frameworks and social equity issues.

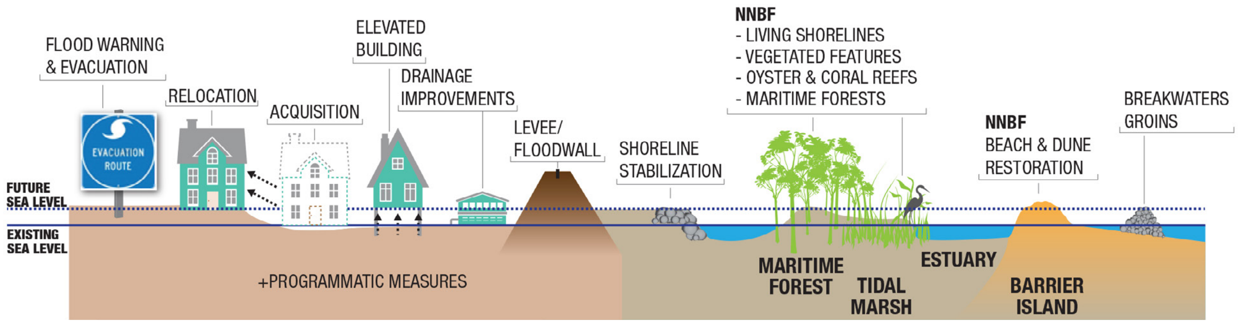


Figure 11. *Coastal sea level rise adaptation will require a mix of natural infrastructure, traditional infrastructure, policies, and programmatic efforts. Courtesy of USACE ERDC.*

The Clean Water Act, the National Flood Insurance Program, state shoreline protection laws, local land use ordinances, erosion and sediment control laws, stormwater management, flood control, and emergency management policies will continue to inform how natural infrastructure can be implemented and coastal areas are protected. Differences in wealth will also affect how individual landowners can adapt to increased flooding from sea level rise and climate change.

Dune preservation and restoration efforts are critical to preserving coastal habitat and providing defenses against coastal flooding. States throughout the Gulf and Atlantic coasts have shoreline protection laws to protect dune systems. Generally, states create jurisdictional areas of dune protection ("setbacks") drawn from seaward lines based on tidelines (e.g., "spring tide" in Florida) and add erosion rates to create a landward setback line on or past a dune where development can occur. Some states use a more fixed approach, drawing setback lines from natural features defined by the sand dunes themselves. Some local governments have implemented dune protection ordinances and setbacks that go above and beyond state law, allowing for additional protective buffers. No states along the Gulf and South Atlantic coasts currently take rising sea levels into account when establishing jurisdictional setbacks.

In estuarine areas, living shorelines are increasingly becoming integrated into the coastal management landscape. Because shoreline stabilization often occurs in intertidal waters or involves "navigable waters" and adjacent wetlands, the USACE becomes involved through its authority under the Rivers and Harbors Act of 1899 and Section 404 of the Clean Water Act *(33 U.S.C. § 403; 33 U.S.C. § 1344)*. The most relevant USACE activities are its authority to issue Nationwide Permit 13 (for armored shoreline stabilization structures) and Nationwide Permit 54 (for living shorelines). In addition to the USACE, most states also regulate estuarine areas through some combination of the following approaches: (1) construction setbacks (buffers), (2) permitting programs regulating activities such as shoreline stabilization in marsh or tidal wetlands, and (3) licensing control of state-owned water bottoms.

While a variety of values such as habitat protection, preservation, aesthetics, and recreation are often considered when decision-makers evaluate stabilization choices, perceived efficacy in controlling erosion so that property is protected is often the most important factor, outweighing all the others.

In the case of living shorelines, increasing confidence in their capacity to control erosion and protect property as well as (or better than) traditional approaches, such as seawalls and bulkheads, will be critical moving forward.

A challenge to integrating natural infrastructure into coastal management is the parcel-by-parcel decision-making used in existing regulatory and incentive-based frameworks as well as the large variation in parcel value and landowner wealth. Individual property owners request permits when they choose to take a stabilization action or disturb a dune, marsh or wetland area. Policies will be needed to promote more comprehensive assessments and management, promoting decision-making that accounts for the effects of multiple stabilization structures on the broader landscapes, instead of individual projects on specific parcels. Policy innovations such as requiring the replacement of hard armoring with natural infrastructure and incorporating sea level rise projections into jurisdictional determinations are needed.

Adapt, Flood or Retreat

Barrier island and coastal communities of the Gulf and Atlantic Coasts will have to adapt or face increasing flood-related problems due to sea level rise. Increasing the resilience of these communities will require a mix of natural infrastructure projects, traditional infrastructure retrofits and policy refinements. Doing nothing is an obvious option, but it will come with regularly flooded roads, stormwater systems and sewer lines that fail to drain properly, more extensive damage during tropical storms, and, eventually, significant loss of land area.

A sociologically controversial idea for sea level rise adaptation is managed retreat, accepting that parts of the coastal landscape are going to be too hard to defend and will require abandonment. Managed retreat requires geographic risk analysis, funds for property buyouts, willing participants, regulation of development and creation of new green spaces.

The beaches, barrier islands, and estuaries of the Gulf and Atlantic Coasts persist in a dynamic balance between coastal erosion processes and deposition of new sediment carried by rivers to the coast. The dynamics of this balance are problematic for fixed property boundaries, and traditional coastal engineering has attempted to hold shorelines in place with hard infrastructure like seawalls and groins. As sea levels rise and as communities on the mainland are hardened in place, salt marshes are unable to migrate landward and are lost due to what is known as coastal squeeze. The loss of these coastal wetlands reduces the natural protections they provide to coastal communities. New techniques will be required for maintaining and protecting coastal property, and natural infrastructure enhancement will be a vital part of increasing coastal resilience to sea level rise.

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REFERENCES

33 U.S.C. § 1344(e)(1) (providing for a general permitting process); Issuance and Reissuance of Nationwide Permits, 82 FR 1860-01 (Jan. 6, 2017). Under NWP 13, "bank stabilization" projects such as seawalls, rip rap, and revetments no more than 500 feet in length are permitted. Issuance and Reissuance of Nationwide Permits, 82 FR 1860-01 (Jan. 6, 2017). Under NWP 54, which was added in 2017, living shorelines are now authorized under the Corps' general permitting process. Issuance and Reissuance of Nationwide Permits, 82 FR 1860-01.

Berkowitz, J. F., Piercy, C., Welp, T., & Vanzomeren, C. (2019). Thin Layer Placement: Technical Definition for U.S. Army Corps of Engineers Applications.

NOAA Office for Coastal Management. 2016. NOAA OCM Digital Elevation Models. https://www.coast.noaa.gov/slr. Accessed 15 Jan 2020.

ADDITIONAL WEB RESOURCES

Coastal Reilience | Green Infrastructure | US EPA
Naturally Resilient Communities (nrcsolutions.org)
Nature-Based Solutions | FEMA.gov
Resilient Nation Partnership Network | FEMA.gov
Engineering With Nature: An Atlas Series – Engineering With Nature (dren.mil)
Resilient Communities and Economies (noaa.gov)
Adaptation Planning Guidebook | Florida Department of Environmental Protection
Coastal Studies Institute Home | ECU Outer Banks Campus
Home Page - Restore America's Estuaries
Start a Coastal Restoration Project · Coastal Restoration (restoreyourcoast.org)
Coastal Flooding Maps – Resilience Community (geoplatform.gov)
USGS Coastal Change Hazards Portal
Sea level | Vital Signs – Climate Change: Vital Signs of the Planet (nasa.gov)
Historical Hurricane Tracks (noaa.gov)
USACE Thin Layer Placement Website

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