Nature-Based Shoreline

OPTIONS FOR THE GREAT LAKES COASTS

UNIVERSITY OF WISCONSIN SEA GRANT INSTITUTE

Cover: Grafton, Wisconsin. *Sara Stathas*

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INTRODUCTION

What Is a Nature-Based Shoreline?

Nature-based shorelines (NBS) use or mimic natural features to stabilize the coast. These natural features can include vegetation, beaches, dunes and reefs. In addition to protecting the coast against erosion and flooding, nature-based shorelines can also benefit ecosystems, aesthetics and coastal processes. NBS approaches are softer or greener compared to conventional hard armoring of the coast. Hard armoring — also called gray infrastructure — includes large rock or concrete structures like rip-rap revetments, sea walls, groins and breakwaters. In many cases, nature-based shorelines use a hybrid of natural and hard features to achieve a desired level of protection from erosion or flooding.

Nature-based shorelines are similar to a number of approaches, including the following:

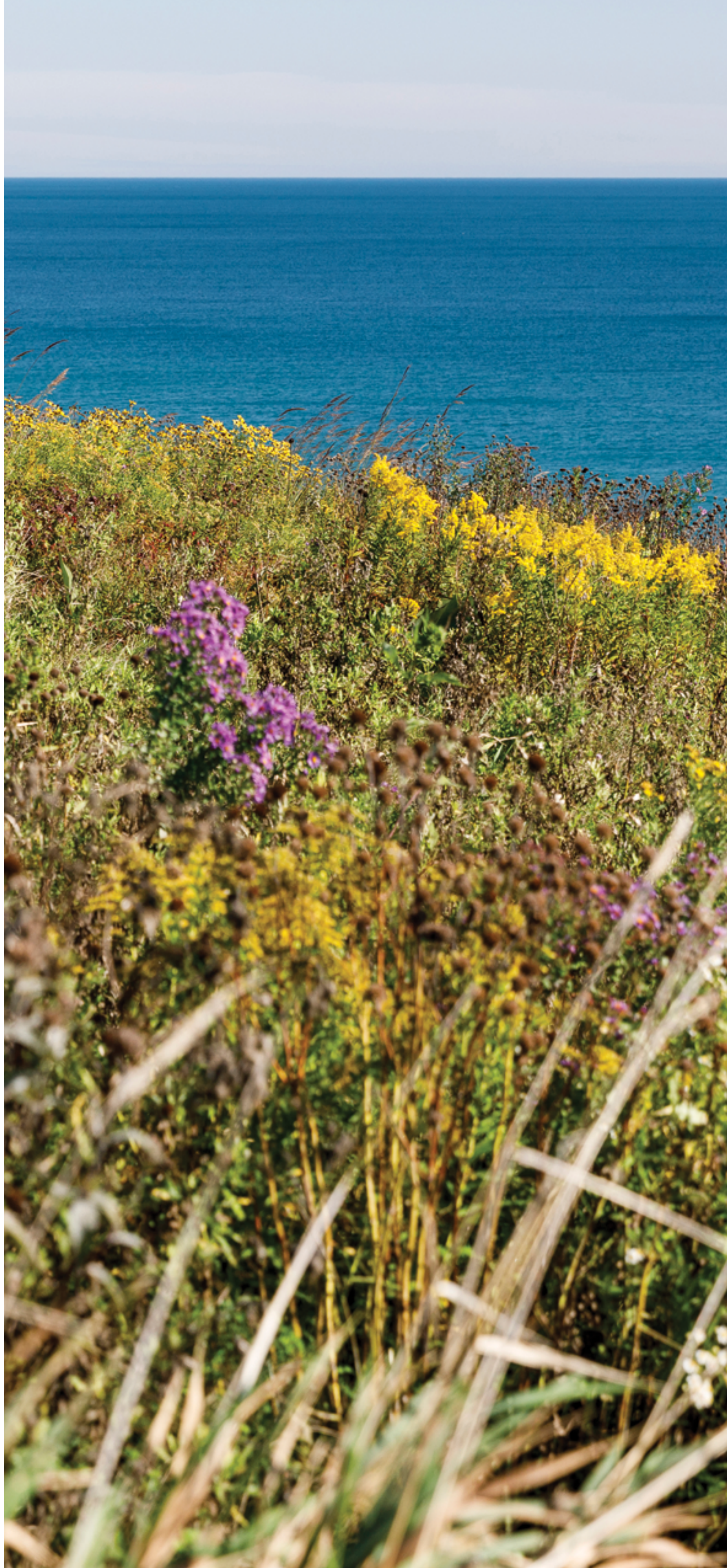
- Living shorelines
- Natural and nature-based features (NNBF)
- Coastal green infrastructure
- Engineering With Nature (U.S. Army Corps of Engineers initiative)

The use of nature-based shorelines is well established along the ocean coasts. In some cases, nature-based shorelines have been shown to be more resilient to hurricane damage than nearby hard armored shorelines (Gittman et al., 2014; Smith et al. 2017; Smith et al., 2018). Natural and nature-based features are also widely used to stabilize streambanks and shorelines of smaller inland lakes. The success of nature-based shorelines in these environments has led to growing interest in the Great Lakes.

This guide describes the different types of NBS techniques that may be suitable for the Great Lakes and includes case studies for each technique to illustrate its use in this region. A glossary of coastal terminology is also included at the end.

This guide is not an exhaustive list of specific NBS techniques. Many NBS variations exist and continue to emerge in the Great Lakes. As more NBS projects are completed throughout the Great Lakes, this guide may be updated to feature emerging NBS techniques.

For a list of options to protect coastal assets beyond NBS approaches, see the Wisconsin Sea Grant Publication "Adapting to a Changing Coast: Options and Resources for Coastal Property Owners."



Types of NBS Techniques in the Great Lakes

The NBS techniques used on the Great Lakes can be broadly classified into six categories. These techniques can often be used in combination to achieve hybrid shoreline protection that maximizes ecosystem benefits. The categories are the following:

Vegetation

Native vegetation planted on the shore to reinforce sediments with its roots, dissipate wave energy and slow erosive runoff and wind.

Nourishment

The placement of clean sediment, often sand, on beaches, dunes or in nearshore waters to replace lost sand or build dunes.

Slope Stabilization

Regrading or reinforcing an eroding or failing bluff, bank or dune to a stable slope to allow vegetation to establish.

Edging

The placement of coir logs, wood or stones at the toe, or base, of the shoreline to prevent erosion and allow vegetation to establish.

Sill

A low-profile structure located in the water just off the shoreline to dissipate wave energy and create an area of protected natural marsh.

Ecologically Enhanced Hard Armoring

Vegetation, textured surfaces or other features added to conventional hard armoring structures to provide habitat and other benefits. This also includes breakwaters built offshore to reduce wave energy at the coast and allow natural features like a beach or vegetation to establish.

Adaptation, the Most Natural Approach

Erosion and flooding are natural processes on the Great Lakes. The most natural response is to adapt and stay out of nature's way. Adaptation options include:

- Move a threatened building back from the coast
- Locate new structures far enough from the shoreline or high enough above the lake that erosion and flooding won't reach them during their useful life
- Enact regulations like setback ordinances that keep new coastal development out of harm's way

Adaptation can often be the most cost-effective option to protect coastal homes. When adaptation actions are not feasible to protect property, nature-based shorelines may be a suitable solution.

Benefits to Nature-Based Shorelines

In addition to protecting the coast, nature-based shorelines have many other benefits, including:

Long-Term Sustainability Nature-based shorelines may be able to adapt to or recover from water level fluctuations or storm events. Recovery may occur either naturally or through maintenance.

Cost Material and construction costs for NBS techniques can be relatively low compared with hard armoring. Note that NBS techniques may have long-term maintenance and upkeep costs.

Natural Coastal Processes NBS techniques seek to mimic the natural processes of the coast, which can lessen impacts to nearby areas. Hard armoring can interrupt sediment transport and alter wave dynamics.

Habitat Vegetation and other natural features improve terrestrial and aquatic wildlife habitat and biodiversity.

Water and Air Quality Vegetation can improve water quality by filtering nutrients and pollutants from runoff. Vegetation also absorbs air pollutants and sequesters carbon from the atmosphere.

Aesthetics A natural-looking shoreline may be more visually appealing than hard armor or an actively eroding shoreline.

Public Access Nature-based shorelines can increase space for recreation. A natural water's edge also makes access to the lake easier than hard armor.

Hybrid Approaches NBS techniques can be used alone or in combination with traditional hard armoring in a hybrid approach to fit a variety of environments.

Challenges to Nature-Based Shorelines

Some specific challenges to the implementation of nature-based shorelines in the Great Lakes include:

High Wave Energy Much of the Great Lakes shoreline is an exposed open coast environment. The high wave energy of the open coast may be too great for some NBS techniques. In these instances, hybrid approaches may be applicable.

Ice Lake ice forces can damage nature-based shorelines. Hybrid approaches, gentle coastal slopes and woody plants like shrubs may need to be used in areas prone to ice damage.

Climate Due to the cold climate of the region, it can be challenging to get coastal vegetation to establish during the short growing season. Plants may need to be started in a greenhouse over winter or irrigated to hasten their establishment.

Fresh Water Many common NBS techniques that work well on the ocean coast incorporate saltwater species like mangroves, oysters and corals that will not survive in the freshwater Great Lakes. NBS techniques that have been developed for freshwater streams and inland lakes may be applicable in suitable wave energy environments.

Highly Altered Shorelines Some areas of the Great Lakes are already heavily armored. It may be difficult to have an ideal nature-based shoreline if coastal processes are severely altered by development. Hybrid approaches may be required in these areas.

Permitting The use of some NBS techniques is relatively new in the Great Lakes. Many agencies do not have well-established permitting processes for NBS techniques yet. Getting a permit may require more effort than for conventional hard armoring. Permitting agencies are improving their knowledge and processes as the field grows.

Design and Construction Nature-based shorelines are a growing field in the Great Lakes. A limited number of engineers and contractors may be comfortable completing these projects. Project planning may be more complicated than for a more conventional hard armor structure. The capacity of contractors and engineers is growing as demand for nature-based shorelines increases.

Evaluating and Comparing NBS Techniques

Several major factors influence what type of NBS technique may be suitable for sites along the Great Lakes. A summary table on the following page contains evaluations of NBS techniques for these factors relative to each other and traditional hard armoring practices. This is followed by expanded sections describing each technique in greater detail, including a case study.

Note that certain NBS techniques may be suitable over a wide range of conditions. A qualified engineer or contractor will consider these and many other factors beyond the scope of this guide to make a final recommendation on what options are appropriate for a given site.

Environmental benefits

The extent to which a technique may benefit the local ecosystem. This can include creating terrestrial and/or aquatic habitat, filtering nutrients and pollutants, or absorbing carbon.

- *High* – Wildlife habitat is restored, created or enhanced.
- *Medium* – Some enhancement to habitat or services occurs.
- *Low* – May offset some of the ecosystem or coastal processes impacts of constructing shore protection.

Wave energy

The type of wave environment that a technique can withstand while still providing protection against erosion and flooding. Techniques that are suitable for higher wave conditions will likely be effective in lower wave conditions, although they may be excessive.

- *High* – Wave energy found on the open coast of the Great Lakes or other areas with a long fetch, or distance over which the wind can blow to create waves.
- *Medium* – Wave energy found in estuaries or somewhat protected open water shores.
- *Low* – Wave energy found in protected harbors, bays or connecting channels with a fetch under one mile.

Slope

The steepness of the beach, dune or bluff on which a technique can be effective while still providing adequate erosion protection. Techniques that are suitable for higher slope conditions may also be effective for lower slope conditions, although they may be excessive.

- *High* – Steep, unstable or actively eroding grades. Vegetation may not be able to establish without additional stabilization.
- *Medium* – Moderately stable grades. Vegetation may be able to establish, perhaps with temporary reinforcement like erosion-control matting.
- *Low* – Stable shores with a shallow grade. Vegetation can establish with a high chance of success.

Cost

The amount of money that may be spent on initial design, materials and construction. Cost ratings are relative to each other and do not represent a linear scale or defined dollar amount.

- *High* – Expensive materials and extensive construction costs.
- *Medium* – Moderate material and construction costs. Also, potentially lesser material costs with extensive construction costs.
- *Low* – Less expensive materials and simpler construction.

Maintenance requirements

The amount of time, effort and money that may be spent on maintaining protective and habitat functions.

- *High* – Regular, extensive maintenance is to be expected, often with high costs.
- *Medium* – Routine maintenance is needed to sustain protective and habitat function.
- *Low* – Routine monitoring and occasional repair as needed.

NBS Techniques Summary

Vegetation
Native vegetation planted on the shore to reinforce sediments with its roots, dissipate wave energy and slow erosive runoff and wind.

Nourishment
The placement of clean sediment, often sand, on beaches, dunes or in nearshore waters to replace lost sand or build dunes.

Slope Stabilization
Regrading or reinforcing an eroding or failing bluff, bank or dune to a stable slope to allow vegetation to establish.

Edging
The placement of coir logs, wood or stones at the toe, or base, of the shoreline to prevent erosion and allow vegetation to establish.

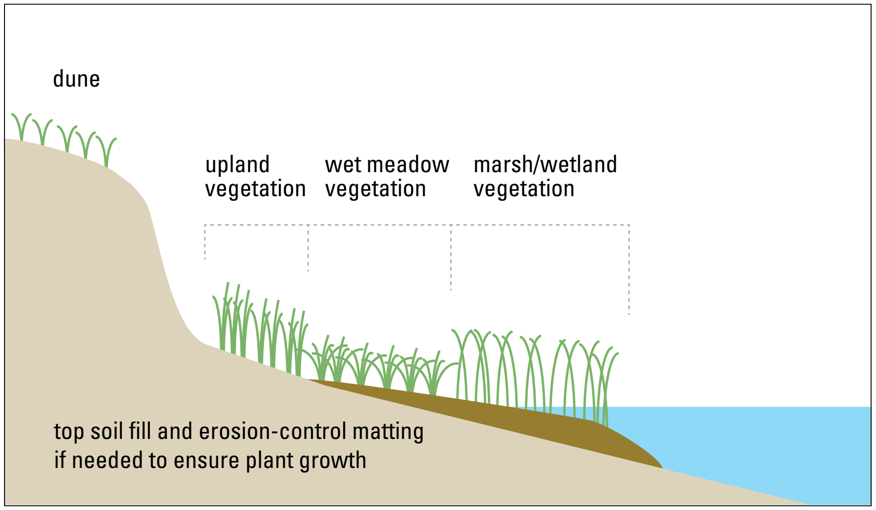
Sill
A low-profile structure located in the water just off the shoreline to dissipate wave energy and create an area of protected natural marsh.

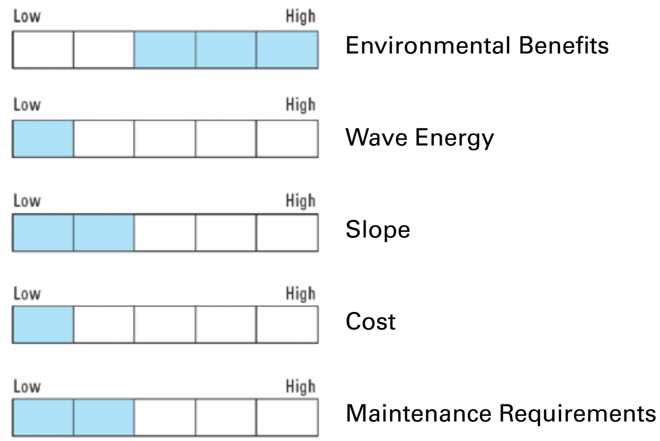
Ecologically Enhanced Hard Armoring
Vegetation, textured surfaces or other features added to conventional hard armoring structures to provide habitat and other benefits.

Hard Armoring
Rock, concrete or steel structures placed along the shoreline to slow erosion such as revetments, seawalls, groins and breakwaters.

Technique	Environmental Benefits (Low → High)	Wave Energy (Low → High)	Slope (Low → High)	Cost (Low → High)	Maintenance Requirements (Low → High)
Vegetation	□□■■■	■□□□□	■■□□□	■□□□□	■■□□□
Nourishment	■■■■□	■■■■□	■■□□□	□■■■□	□■■■■
Slope Stabilization	□■■■□	■■■■■	□□■■■	□■■■□	■■□□□
Edging	□■■■□	■■□□□	■■■□□	■■□□□	■■■□□
Sill	■■■□□	□■■□□	■■■□□	□■■■□	■■■□□
Ecologically Enhanced Hard Armoring	■■□□□	□□■■■	□■■■■	■■■■■	■■□□□
Hard Armoring	■□□□□	□□□■■	□■■■■	□□■■■	■■■□□

VEGETATION





Overview

Native vegetation with deep root networks can help stabilize coastal beaches, dunes and bluffs. Under the ground, roots hold and add strength to the soil while also absorbing excess moisture. Above the ground, vegetation slows the speed of erosive runoff and wind. Native vegetation also provides habitat and can filter nutrients and pollutants from runoff. In low wave energy environments, vegetation alone may provide sufficient protection to the shore. In higher wave energy environments, vegetation is often used with other practices that reduce wave energy and erosion to increase the likelihood of plant survival. Temporary fencing may also be needed to limit grazing by waterfowl and other wildlife as vegetation establishes.

Maintenance

Vegetation will need to be regularly maintained through yearly debris clean up, weeding, watering and occasional treatment to remove invasive species. Maintenance is likely to be more intensive when vegetation is first establishing. More mature living shorelines may be able to repair themselves over time and migrate with changing lake levels. Occasional replanting may be needed due to winter die-off and storm or ice damage.

Benefits

- Enhances habitat and ecosystem quality
- Lasts for a long time if well established and maintained
- Requires potentially simple and inexpensive construction

Challenges

- Dissipates limited amount of wave energy
- May present difficulty in establishing vegetation in competition with invasive species
- May require yearly maintenance and occasional replanting

Related Options

Vegetation can be used with other methods like edging, sills and breakwaters in moderate or high wave energy environments.

American beachgrass *(Ammophila breviligulata)* planted at Loyola Park in Chicago by the Loyola Dunes Restoration volunteer group in collaboration with the Chicago Parks District. The vegetation holds beach sand against wind erosion and has also been effective at reducing upland flooding from wave action. *Ann Whelan*

A restoration project at Wisconsin Point included revegetating the dunes, which limits wind erosion. Boardwalks reduce foot traffic over the restored vegetation. *City of Superior*

Resources

Wisconsin Shoreline Plants and Landscaping

This University of Wisconsin-Extension document provides guidelines for shoreline landscaping management and a list of suggested plants for Wisconsin shorelines.

go.wisc.edu/4s90h8

Reconnecting With our Great Lake's Coast

This bulletin from the Ohio Department of Natural Resources summarizes research on the benefits of shoreline vegetation on fish species diversity along both armored and unarmored coasts in Lake Erie. It also details a few methods to add natural features into shore protection.

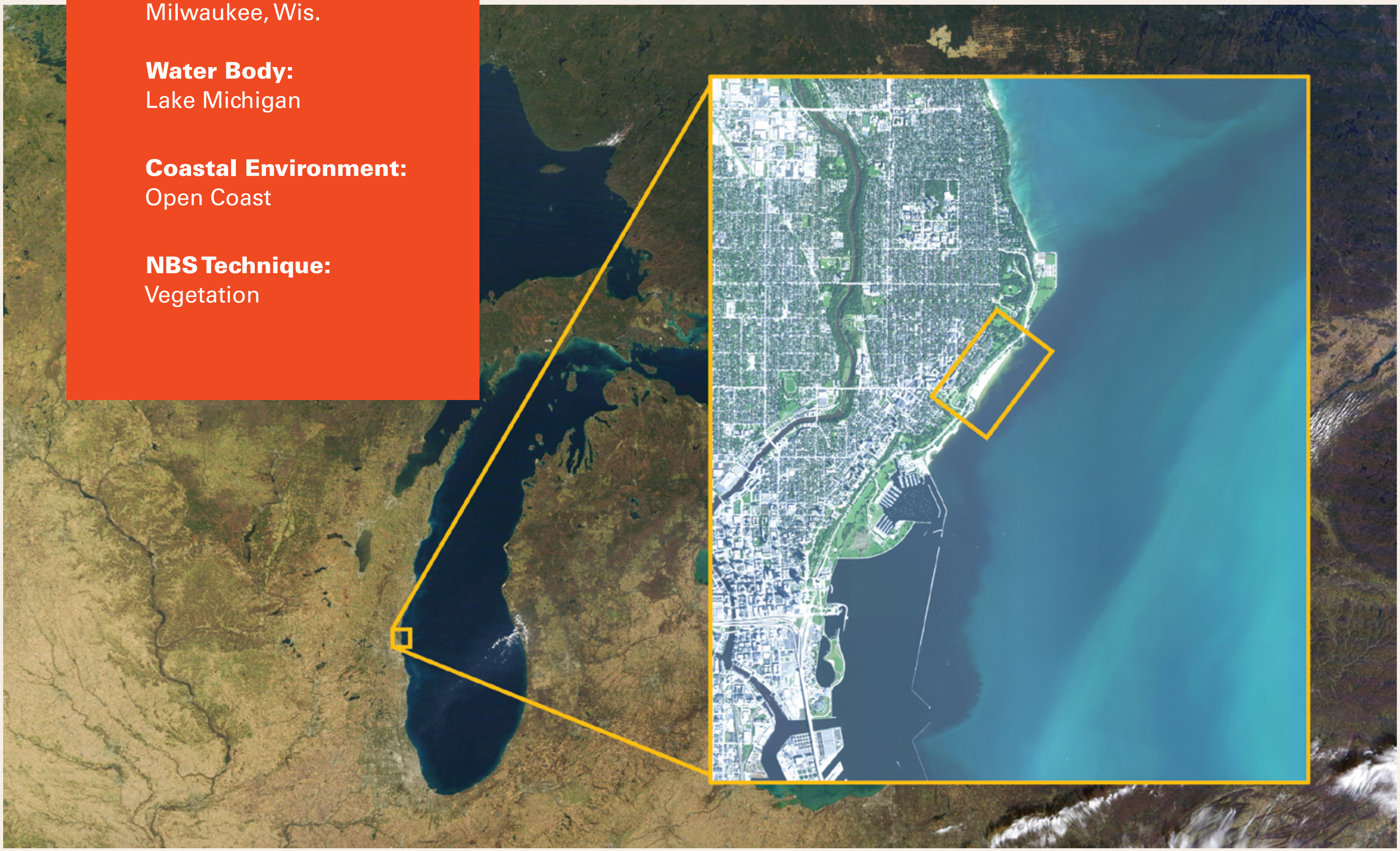
go.wisc.edu/2y15jr

Location:
Milwaukee, Wis.

Water Body:
Lake Michigan

Coastal Environment:
Open Coast

NBS Technique:
Vegetation



Case Study: Bradford Beach

Before Vegetating (2007) This aerial image of the beach before the project shows areas of ponded stagnant water and wet sand. The beach lacks much vegetation except for a narrow buffer of turfgrass by the adjacent roadway. *David Mickelson*

After Vegetating (2019) Two of the six vegetated swales, which have improved water quality and added native plant species to the beach. *Capt. Dennis Carr*

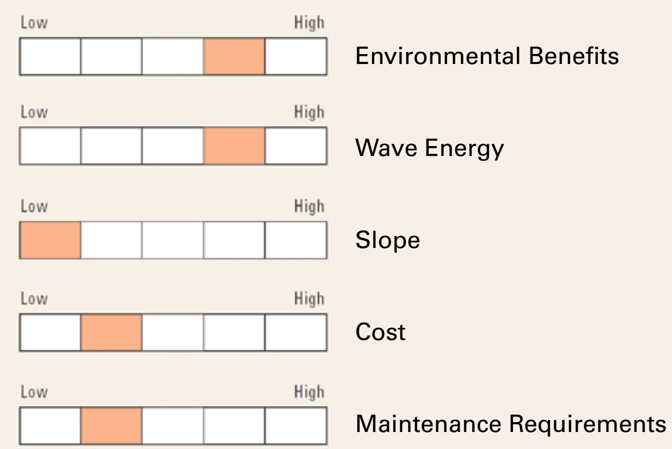
Overview

Vegetation was planted in and around bioswales at Bradford Beach in downtown Milwaukee to improve water quality. Bioswales are shallow depressions that collect stormwater runoff and filter out pollutants as the water soaks into the ground. Prior to the project, Bradford Beach was frequently closed due to high levels of bacteria brought to the beach by stormwater runoff. Milwaukee County led this effort in collaboration with the Milwaukee Metropolitan Sewerage District, the University of Wisconsin's Great Lakes WATER Institute, Milwaukee County's Public Works and Parks departments, the Wisconsin Department of Natural Resources, the city of Milwaukee and several corporations. The cost to construct five standard infiltration basins was around $200,000. A sixth structured basin included a retaining wall and modifications to a nearby parking lot for a total cost of around $450,000. Note that this project cost more than a typical coastal vegetation project due to the construction of the bioswales.

Design

The bioswales were placed around storm sewer discharge pipes and a parking lot at the beach. The bioswales were designed to infiltrate 90% of the stormwater into the ground. The native vegetation planted in the bioswales was selected for root structures that anchor the sand, filter pollutants from the water and allow water to infiltrate into the sand. Dune grass was also planted on the slope of the bioswales to prevent erosion. The wide beach provides the bioswales some protection from the high wave energy of the open coast. A gull deterrent program was also used to reduce gull populations to further combat beach bacteria.

Bioswale along the beach with well-established native vegetation. *Stevan Keith*



Results

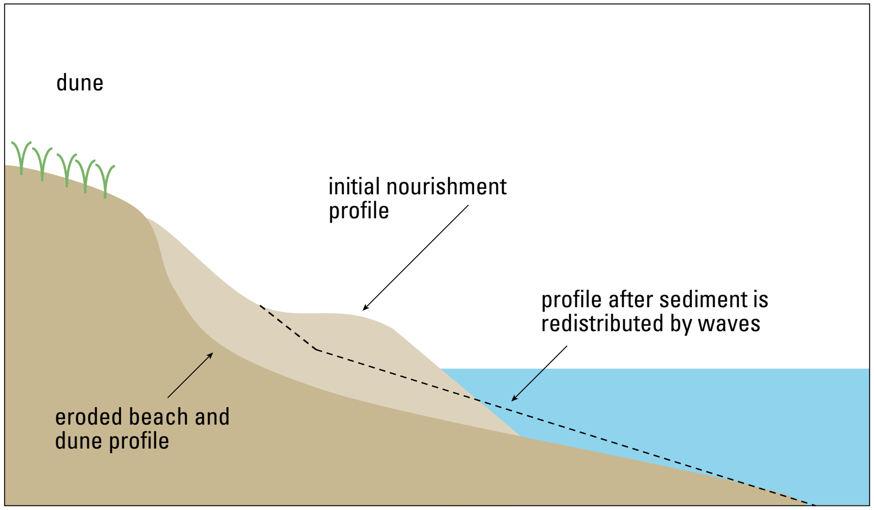
Following this project, Bradford Beach earned the Blue Water certification from the Clean Beaches Council. The beach has experienced lower levels of bacteria and fewer beach closures, as well as an increase in visitors. The two-year maintenance plan for the basins has involved inspections, debris removal and weeding. Standing water does occur occasionally at the beach when heavy rainfall overflows the bioswales, and one of the basins was damaged by an extreme rainfall event. During record high Lake Michigan water levels in 2020, bioswales on the narrower part of the beach have suffered some damage while those on the wider part of the beach have remained intact. Overall, the bioswales have been a success and the design has already been applied to other sites.

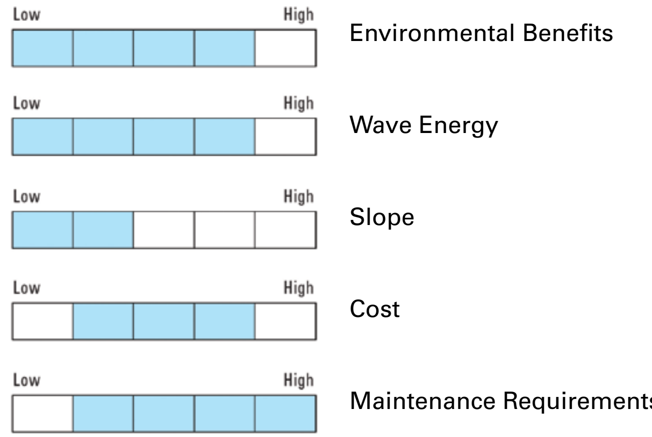
Lessons Learned | Bradford Beach

Milwaukee County project leaders emphasized that collaboration with partners was vital to the success of the project. They also learned the importance of allocating sufficient funds for maintaining the functionality of the swales over time.

Vegetation was used in a high wave energy environment by siting the basins at the landward extent of a wide beach. Bioswales on the widest portion of the beach were not damaged during record high Lake Michigan water levels.

NOURISHMENT





Overview

Nourishment is the placement of clean sediment, often sand, on beaches or dunes or in nearshore waters. Nourishment is typically done to replace sediments that have been lost due to erosion. The nourished material acts as "sacrificial" sediment that will erode over time unless the root causes of the erosion are addressed. Nourishment can also increase beach slope and reduce water ponding to improve water quality. The grain size of the nourishment material should be similar to or slightly coarser than existing sediment at the site. Nourishment material often comes from an inland source or a nearby dredging project. In many applications, the sand is spread along the beach mechanically. Sand may also be placed in the nearshore waters to allow gentle, non-storm waves to move the sand onto the beach naturally.

Maintenance

Most sites will likely require re-nourishment every few years as the sand is naturally removed by erosion, especially during high water periods. Sand fencing can help retain sediment against wind erosion, especially in the late fall and winter.

Benefits

- May beneficially reuse clean dredged material
- Improves beach health, appearance and usability
- May potentially supply sediment to adjacent properties

Challenges

- Requires clean, appropriately sized sediments that may be costly, difficult to find and challenging to permit
- May require re-nourishment every few years to replace sediments naturally lost to erosion
- Can cause ecological disturbances during placement

Clean sand dredged from Kenosha Harbor in Wisconsin is pumped to a beach placement site. *Chin Wu*

Related Options

Vegetation can be used to reduce erosion of nourished sediment and add habitat. Breakwaters may help retain nourished sediment (but may have negative effects on adjacent shorelines).

Clean, coarse-grained sediment dredged from the Two Rivers Harbor in Wisconsin is pumped to the placement site and spread across the beach with heavy machinery. *Jim Killian*

Resources

The American Shore and Beach Preservation Association

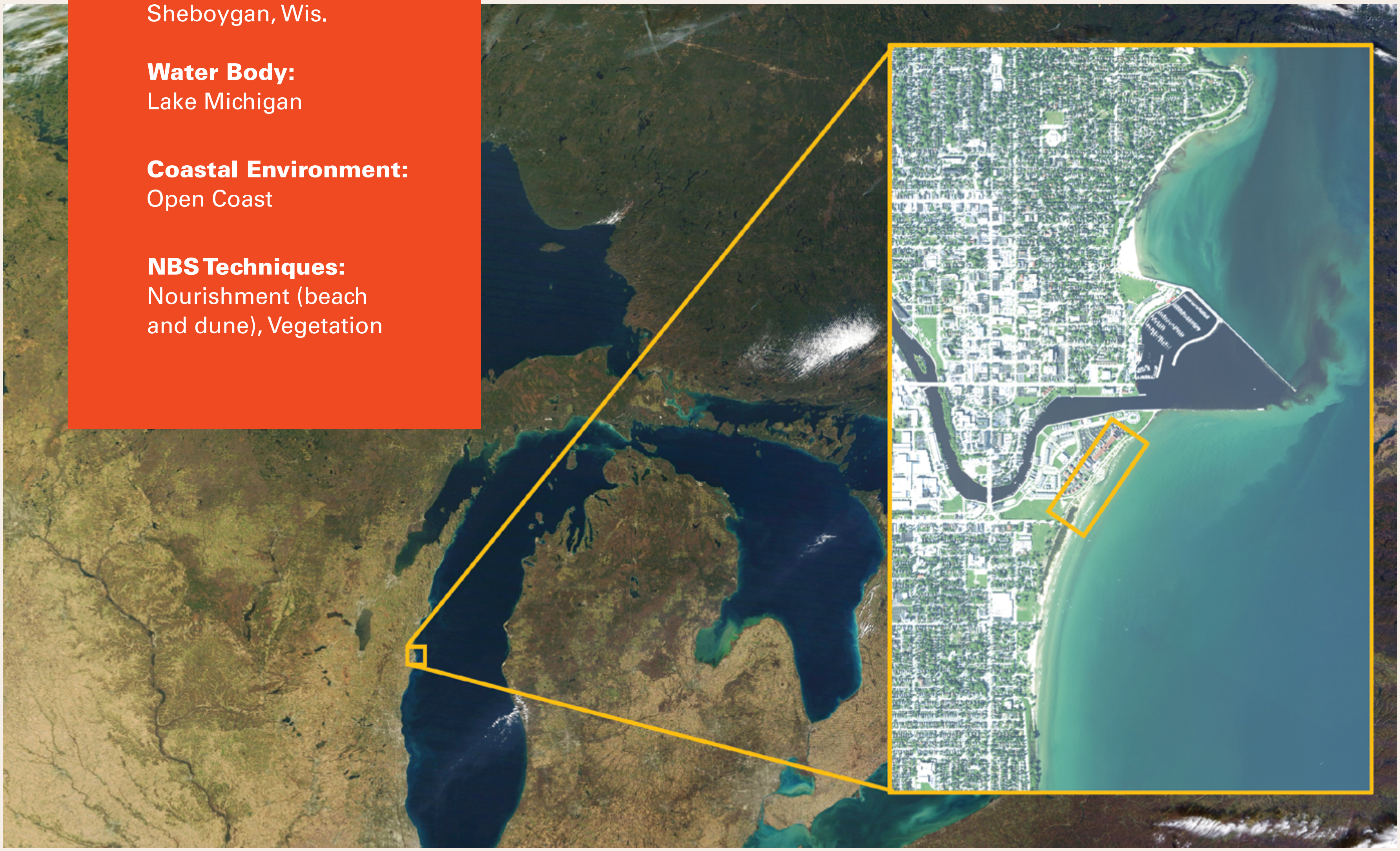
This organization's website contains a database of existing beach nourishment projects and publications about the process of beach nourishment.

asbpa.org

How Beach Nourishment Projects Work

This United States Army Corps of Engineers (USACE) assessment has detailed information on the function of beaches, how they erode and how to protect them. It provides some examples of beach nourishment projects and how they protect shorelines from large storm surges.

go.wisc.edu/7838y2



Location:
Sheboygan, Wis.

Water Body:
Lake Michigan

Coastal Environment:
Open Coast

NBS Techniques:
Nourishment (beach and dune), Vegetation

Case Study: Blue Harbor Beach

Before Nourishment (1976) Concrete rubble on the shoreline provided erosion protection for oil storage tanks. *Dave Mickelson*

After Nourishment – Low Lake Levels (2012) The beach and buried revetment (left half of shoreline in image) several years after the nourishment project. *USACE*

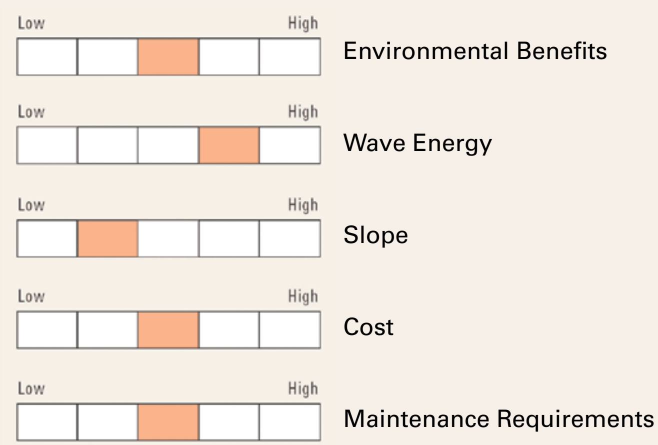
Overview

The city of Sheboygan transformed a hardened industrial shoreline that had been deteriorating for many years after the shutdown of a coal port and oil refinery into a recreational beach that provides protection for a new resort and conference center. The area now known as Blue Harbor Beach spans a nearly half-mile distance. The project included beach nourishment and construction of a sand-buried revetment that functions much like a dune. Native vegetation was also established on the beach and dune system.

Design

The design chosen needed to both protect the conference center and beach from wave erosion and high water levels and also occupy minimal space to allow room for the upland development. Beach and dune nourishment combined with a revetment were chosen to provide protection for the large investment as well as create recreational and aesthetic amenities. The revetment was constructed back from the intended shoreline and then covered in sand planted with native dune grass and trees to act like a dune. Sand was placed in front of the buried revetment to create a nourished beach and dune system. Historic erosion rates and wave energy records were used to design the beach profile and revetment. Under low lake levels, sand deposited by the waves builds up the beach in front of the revetment, functioning much like a natural dune and beach system. Under high water levels, waves erode the sand, but the revetment, which may become exposed, prevents more severe erosion of the shore. As lower water returns, the sand will build back up to re-establish the dune and beach system, although re-nourishment may be required to supplement the natural processes.

After Nourishment – High Lake Levels (2019) Beach has been inundated by high water levels. Sand that had buried the revetment has been eroded but the now-exposed revetment is preventing further erosion. *Capt. Dennis Carr*



Results

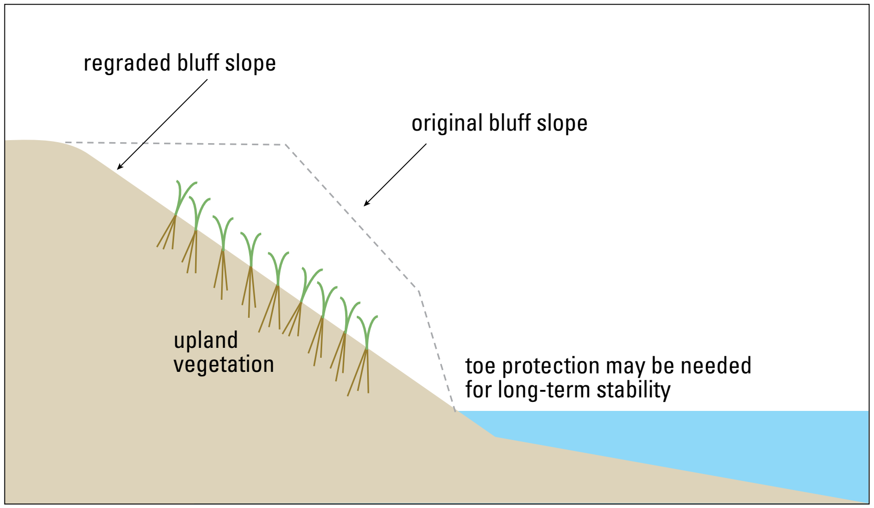
The nourished dune and beach system created an aesthetically pleasing shoreline that re-established natural coastal processes and habitat. Monitoring has revealed that the beach has been decreasing in size since construction. This is likely due to a large harbor jetty to the north, which blocks sediment transported along the shore by waves that would normally replenish the beach. High water levels on Lake Michigan have also inundated the beach and allowed waves to erode away the sand that had buried the revetment. The now-exposed revetment is preventing further erosion as designed. Future re-nourishment has been recommended to replenish lost sand and raise the grade of the beach to reduce bacterial contamination.

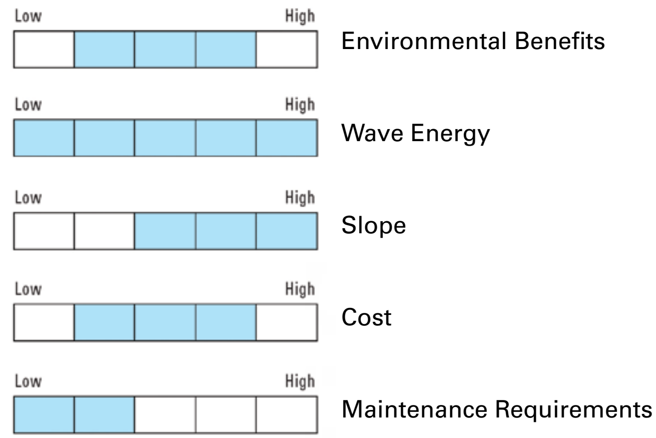
Lessons Learned | Blue Harbor Beach

As with most beach nourishment projects, subsequent maintenance and nourishment projects are required to maintain the beach over longer time scales.

Nourishment was used in a high wave energy environment as part of a buried revetment, which has prevented large-scale erosion in extreme events.

SLOPE STABILIZATION





Overview

Stabilization of a bluff, bank or dune can reduce the risk of slope collapse and subsequent recession of the coast. For a given soil type, the steepest angle for which the soil is stable against collapse is known as the "stable slope angle." Regrading slopes to a stable angle can slow erosion and allow vegetation to establish on the slope face. Terracing the slope with retaining walls is another option. Additional methods may incorporate geogrids, geotextiles, biodegradable matting or other engineered products to reinforce the slope. Groundwater drainage systems may be required in some cases where excess groundwater is reducing soil strength. These stabilization methods do not stop erosion directly at the shoreline, so in some cases toe protection may be needed to reduce wave erosion and ensure the slope remains stable over time.

Maintenance

Vegetation may need to be maintained with watering (at least until it's established), replanting and/or invasive species control.

Benefits

- Stabilization prevents or reduces risk of slope failure
- Vegetation improves appearance of the eroding area
- Stabilized slopes can increase area for vegetation and habitat

Challenges

- Construction may be costly, especially if site access is difficult due to slope instability
- Existing upland buildings may limit the extent of regrading that can occur
- Unaddressed toe erosion can destabilize a regraded slope

Related Options

Vegetation can be used alone on shallower slopes. Sills, edging or other nature-based solutions can be used for toe protection along the shore.

A slope stabilization project in the Milwaukee River estuary that features grading, biodegradable matting and vegetation. Some toe protection was also used. *Marek Landscaping*

Comparison between a failing slope (left) and a stabilized slope (right) at Bender Park in Milwaukee. Regrading, groundwater drainage and native vegetation were used to stabilize a portion of the park. *Adam Bechle*

Resources

Stabilizing Coastal Slopes on the Great Lakes

This Wisconsin Sea Grant fact sheet discusses warning signs of slope instability and several strategies to stabilize slopes.

go.wisc.edu/tx697c

Sand Dune Stabilization

This Michigan Department of Environment, Great Lakes and Energy (formerly Department of Environmental Quality) publication describes best management practices for minimizing impacts to dunes and restabilizing dunes that have been impacted or eroded.

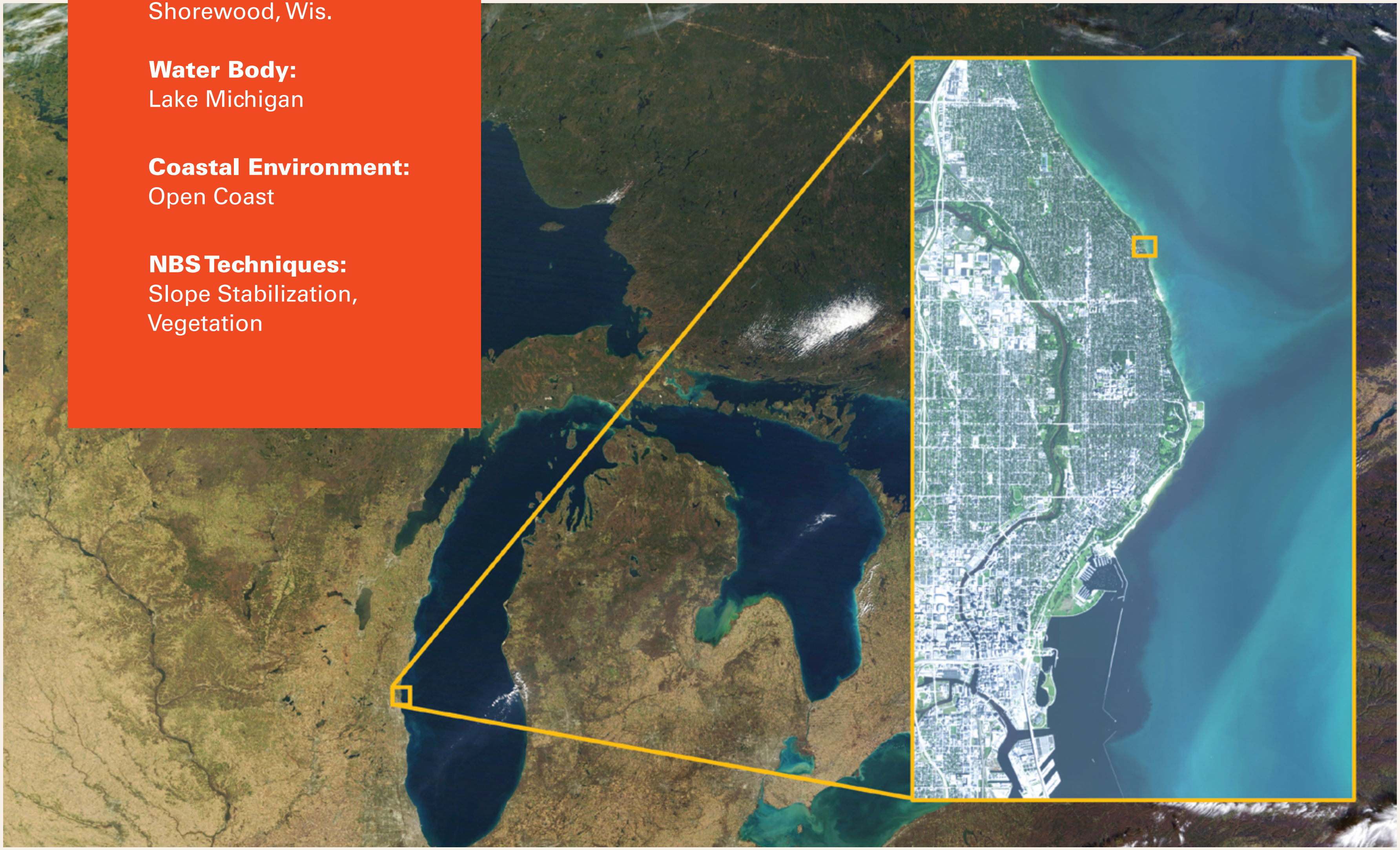
go.wisc.edu/5ip6cn

Location:
Shorewood, Wis.

Water Body:
Lake Michigan

Coastal Environment:
Open Coast

NBS Techniques:
Slope Stabilization,
Vegetation



Case Study: Former University of Wisconsin-Milwaukee Chancellor Residence

Overview

The upper portion of the bluff at the former University of Wisconsin-Milwaukee Chancellor Residence was very steep and had receded to within eight feet of the home. The base of the bluff had already been armored with an existing stone revetment, so wave energy was not a major concern at the site. The upper bluff slope was terraced with a proprietary vegetated retaining wall system to stabilize the slope and add several feet of bluff-top yard space. The project also included a deck and stairs anchored into the bluff and a path to provide shoreline access.

Design

Because of the instability of the bluff and the lack of space between the edge of the bluff and the residence, terracing with a vegetated retaining wall was chosen to enhance stability. A retaining wall resists the sliding forces of the soil to stabilize the slope over a shorter horizontal distance than cutting back the slope to the soil's stable angle. The retaining wall used was a proprietary Filtrexx® GreenLoxx® LivingWall™ system. In this system, geogrids and soil anchors were used to reinforce a wall of Filtrexx tubes filled with compost growing media and native plant seed. Plugs and plantings were used to supplement this vegetation when needed. The native species were chosen for their long roots to help anchor soil and prevent erosion. An irrigation system was also installed to water the plants.

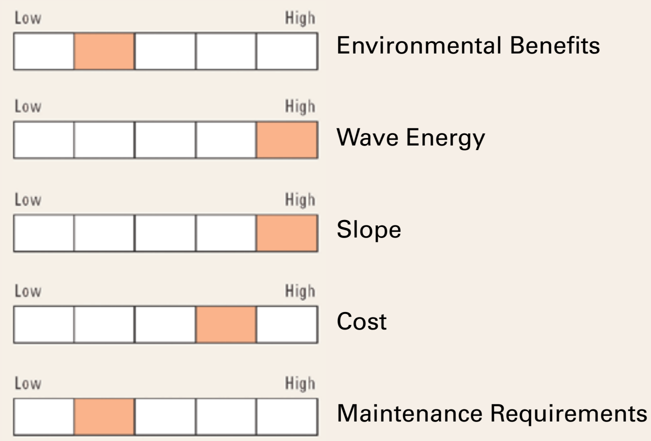
Results

The LivingWall system has stabilized the upper bluff slope near the residence, and the establishment of vegetation creates a nice appearance for the slope. General maintenance and cleanup are done routinely. Invasive species have to be treated on occasion. This project received a 2015 Award of Merit from the Wisconsin Chapter of the American Association of Landscape Architects in the Residential Category.

Before Before stabilization, the bluff was failing very close the residence, indicated by the steep unvegetated slope close to the home. *Marek Landscaping*

After Stabilization of the upper slope incorporated native vegetation, improving the aesthetic and recreational value of the property. *Marek Landscaping*

Before Oblique aerial image (2012) of the site before stabilization with a relatively unvegetated upper bluff slope, especially the particularly steep section just feet from the residence. *USACE*

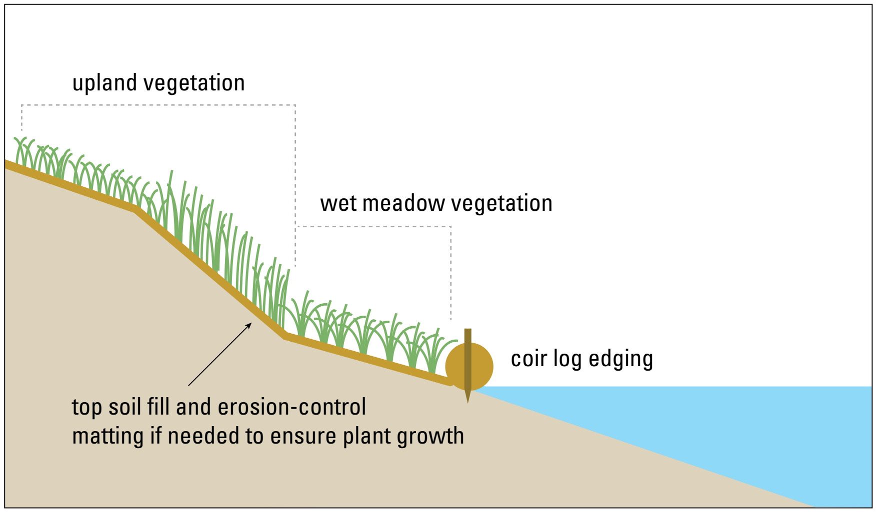


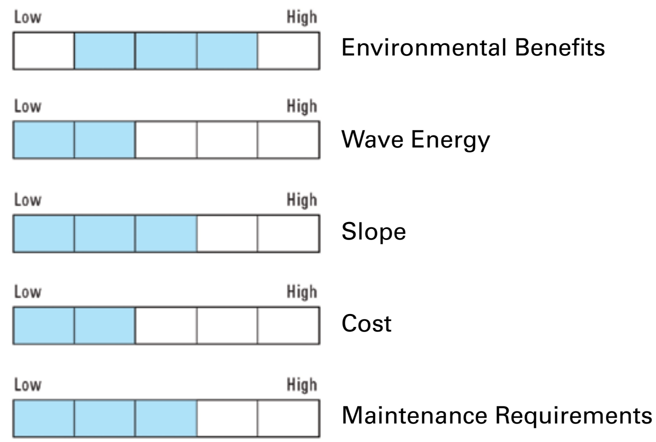
After Oblique aerial image (2019) of the stabilization project with the vegetated terrace wall and new staircase near the residence, as well as a revegetated bluff face. *Capt. Dennis Carr*

Lessons Learned | Former UWM Chancellor Residence

A terrace stabilization with a small footprint was selected for this site, primarily due to limited space between the bluff-top edge and the residence. The LivingWall system also minimized issues with access and construction that would have been required with other stabilization options like cutting or filling.

EDGING





Overview

Edging is the placement of erosion-resistant materials along the toe of the shoreline in low to moderate wave environments. The purpose of edging is to prevent erosion, allowing vegetation to establish on the slope. A variety of materials can be used as edging based on the wave environment, including coir logs, logs or stones. This practice is typically used in combination with shoreline stabilization methods such as erosion-control matting. Edging is generally smaller than a revetment and closer to the shoreline than a sill or breakwater.

Maintenance

Edging materials should be inspected for displacement or damage and repaired as needed. For example, coir logs may need to be re-staked. Maintenance includes yearly debris clean up and occasional weeding and replanting.

Benefits

- Has a lower cost and less complex construction than sills, revetments and breakwaters
- Can be installed with a low impact to existing ecosystems
- Can also provide stormwater filtration

Challenges

- Provides less shore protection than other structural elements
- May be a barrier for access to the shoreline for wildlife; gaps in edging may be needed for habitat connectivity
- May be susceptible to ice damage

Rock edging used to protect upland vegetation from waves and the overwash of beach sand into the vegetation on Lake Superior in Grand Marais, Minn. *Melanie Perello*

Related Options

Sills will provide more protection in moderate wave energy environments. Vegetation can be used alone where wave energy is low enough.

Coir log edging on Maple Lake, Mich., an inland lake with low wave energy. *Brian Majka*

Resources

Michigan Natural Shoreline Partnership

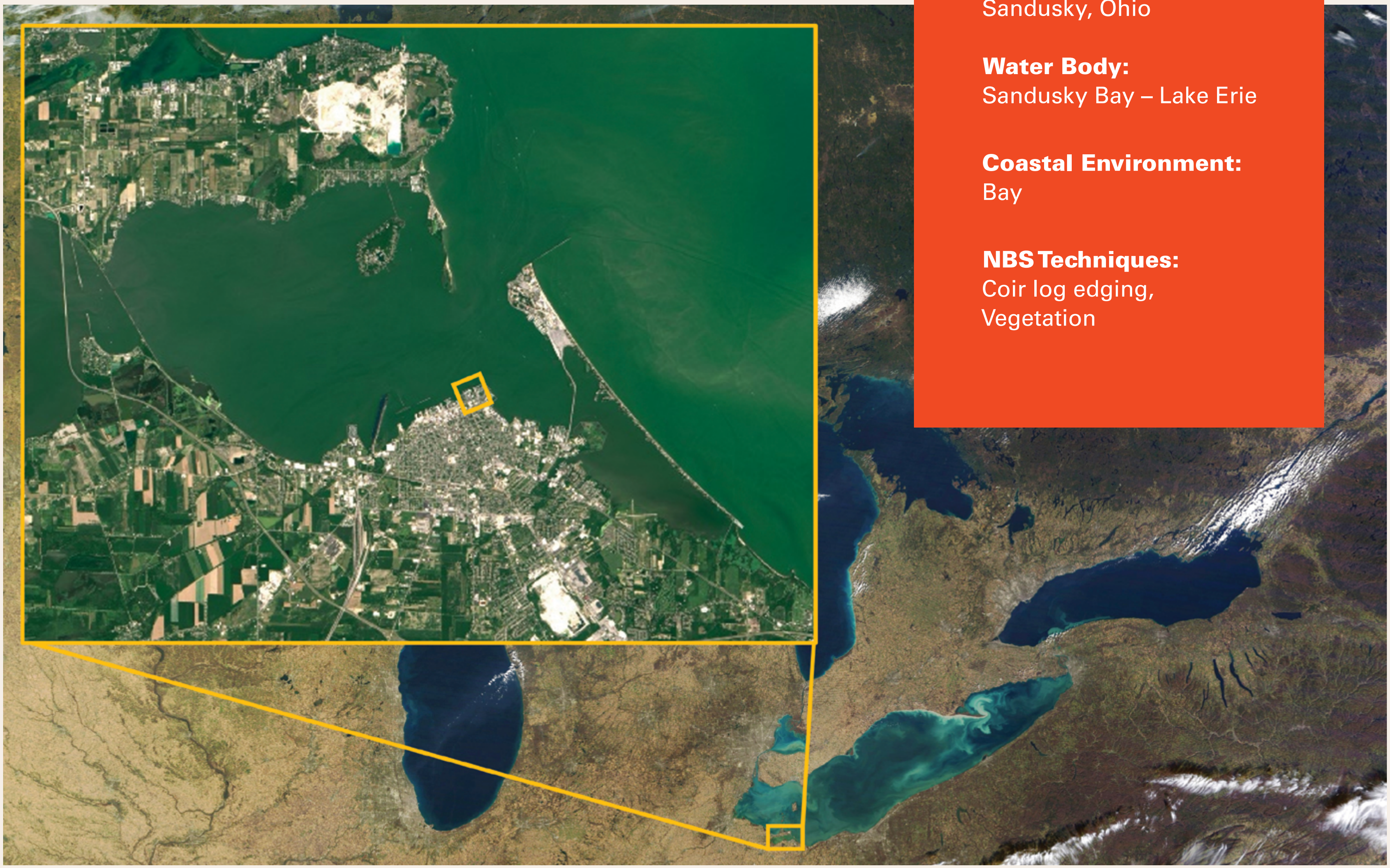
The Michigan Natural Shoreline Partnership has several resources on living shorelines and edging focused on inland lakes. The demonstration sites, lists of native plants and lists of certified contractors may be useful in understanding nature-based shorelines in low wave energy environments.

mishorelinepartnership.org

Delaware Living Shorelines Committee

This website features an overview of living shorelines on Delaware's Atlantic Coast and tips on the steps to implement them. Traditional and hybrid approaches are featured.

delawarelivingshorelines.org



Location:
Sandusky, Ohio

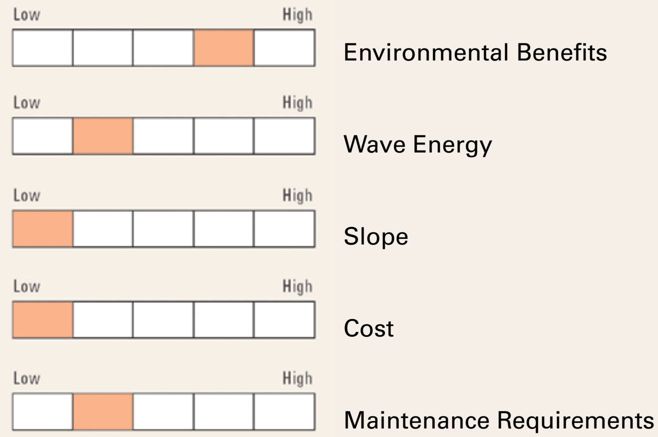
Water Body:
Sandusky Bay – Lake Erie

Coastal Environment:
Bay

NBS Techniques:
Coir log edging,
Vegetation

Case Study: Shoreline Park

Before A turfgrass shoreline was eroding and visually unappealing.
Erie Soil and Water Conservation District



After Edging helped native vegetation establish to stabilize the shoreline. Visual appeal has also improved. *Erie Soil and Water Conservation District*

Overview

Edging and native vegetation were installed at Shoreline Park in Sandusky Bay, which was both losing land to erosion and turning foul due to goose droppings. Coir log edging was used to slow erosion at the toe of the shoreline as an alternative to adding a stone revetment in this sheltered, low wave energy bay on Lake Erie. The existing turf grass slope was replaced with erosion-control matting planted with native vegetation to secure the soil and deter geese from the area. The project was organized by the city of Sandusky and the Erie Soil and Water Conservation District staff and completed by staff and volunteers.

Design

The coir logs were staked in place at the toe and 2–6 inches of top soil was added behind the logs to create an even slope and planting bed. Erosion-control matting was placed on the slope and switch-grass and prairie cordgrass were planted. These deep-rooted plants help hold the soil against erosion and grow several feet tall to deter geese from accessing the shoreline. Little bluestem was planted further up the slope. The native vegetation was grown in a green-house before planting to hasten establishment. The work was done in sections, with the planted vegetation fenced off to allow it to establish. Once the vegetation in a section had taken hold, the next section was installed and the fencing reused.

Results

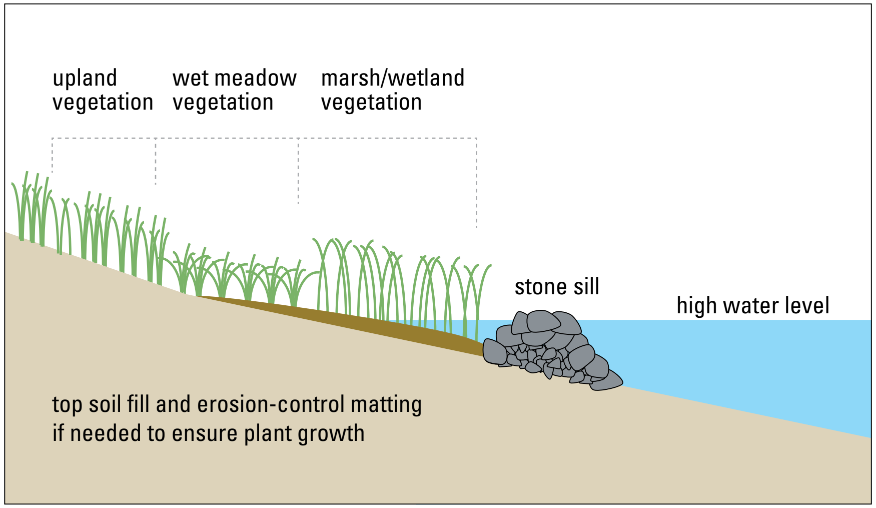
For the first two years after the project was completed, extensive weeding was required. Every spring the area was mowed high. Some supplemental planting was required in areas where the vegetation was sparse. The city of Sandusky has also made some aesthetic changes over time but continues to enjoy the natural shoreline.

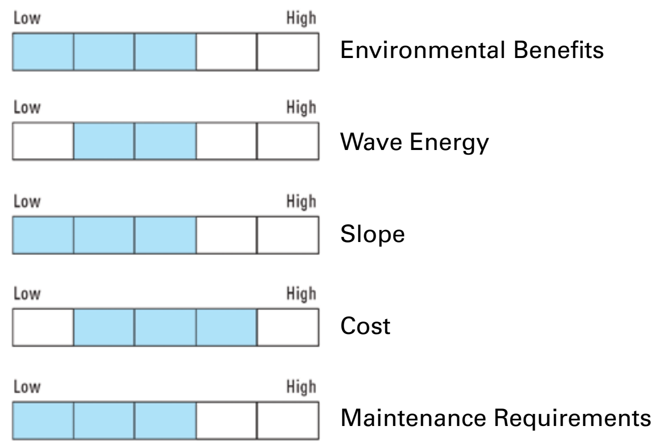
Educational signage informing visitors of the benefits of the edging project.
Erie Soil and Water Conservation District

Lessons Learned | Shoreline Park

This project was completed with the assistance of volunteers. This can be a great way to get the community involved in restoring the community's parks and shorelines.

SILL





Overview

A sill is a low-profile structure located in the water just off the shoreline. Sills are typically designed at a height that emerges just above the expected high water level, though some sills may be designed to be fully submerged. The sill dissipates wave energy as waves break when they pass over the structure. The area of reduced wave energy behind the sill is planted with native marsh and shoreline vegetation. The vegetated marsh area provides aquatic habitat and further protects the shore from erosion. Sills are typically constructed of rock but can also be made of logs or other organic materials. Gaps in the sill are designed to allow water circulation and habitat connectivity between the shore and water. Over time, the area between the sill and shoreline may fill with sediment, especially along sand-rich shorelines. Sills are generally smaller and closer to the shore than breakwaters but are larger and further offshore than edging.

Maintenance

The sill structure should be inspected for damage by waves or ice and repaired as needed. Debris may collect behind the sill and need to be cleaned out. Marsh vegetation may need to be maintained with occasional replanting, weeding and invasive species control.

Benefits

- Creates sheltered aquatic habitat
- Can provide stormwater filtration
- Dissipates more wave energy than vegetation alone

Challenges

- May cause scour in front of the sill and accelerate erosion of adjacent properties
- May pose navigation hazard if the sill structure is periodically submerged and hidden from view
- May pose challenges with the establishment of marsh vegetation with variable water levels

Related Options

Edging can be used in lower wave energy environments. Breakwaters can be used in higher wave energy environments but are larger and more expensive.

A rock sill in Allouez Bay in Superior, Wis. *Adam Bechle*

A rock sill built near the Center Point Bay Marina in Muskegon Lake, Mich. *Brian Majka*

Resources

VIMS Design Options for a Marsh Sill

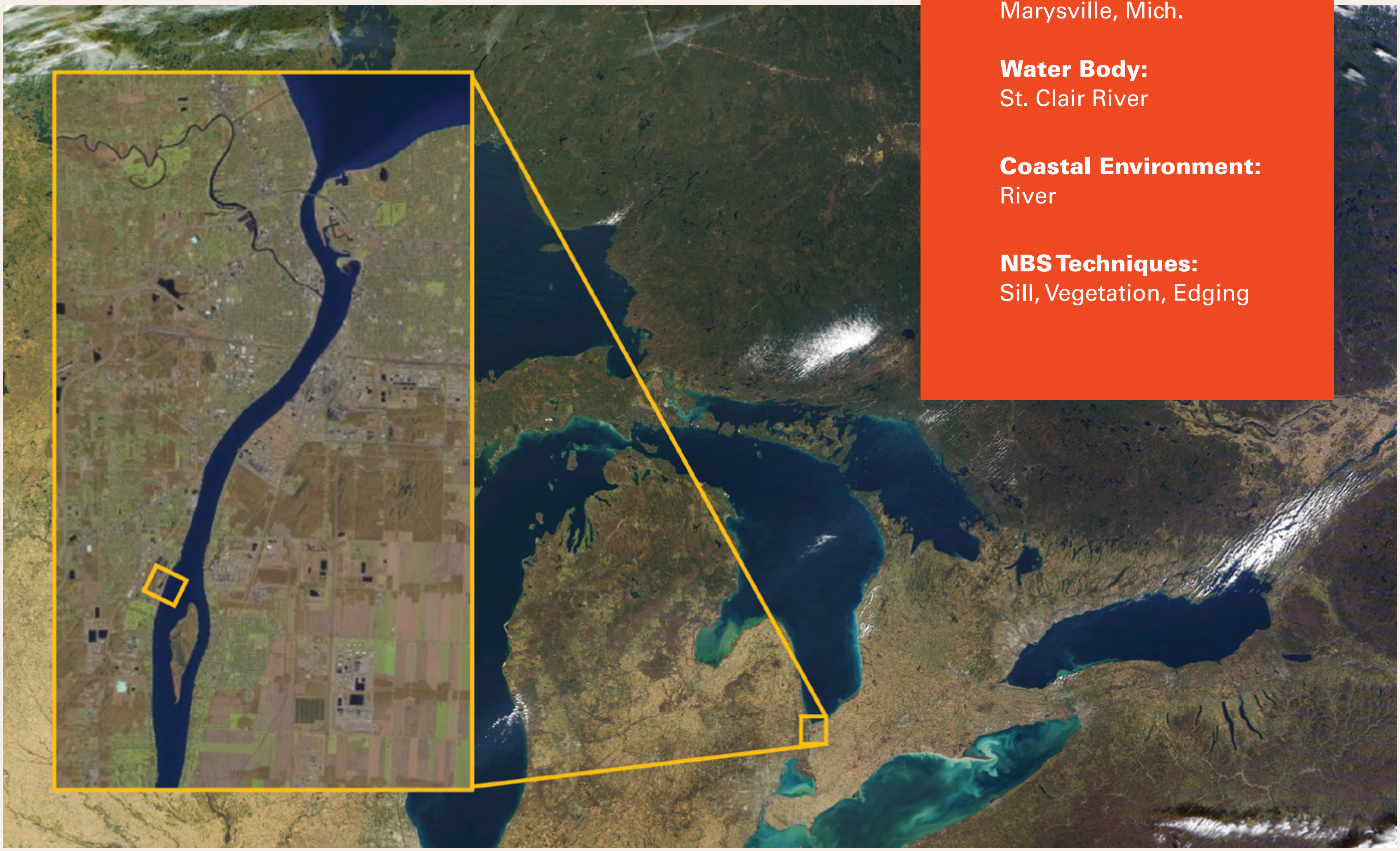
The Virginia Institute of Marine Science has a variety of resources for marsh sills, including a list of site considerations and guidelines.

go.wisc.edu/6u0af9

North Carolina Marsh Sill Evaluation Project

The North Carolina Department of Environmental Quality has evaluated marsh sill projects in the state. They have issued a variety of reports on the results of these projects.

go.wisc.edu/sjhgu5



Location:
Marysville, Mich.

Water Body:
St. Clair River

Coastal Environment:
River

NBS Techniques:
Sill, Vegetation, Edging

Case Study: Marysville Shoreline

Before The area was protected with a steel sheet pile seawall that had become unstable and provided limited environmental benefits. *Barry Kreiner*

After – Low Water The area was protected by a sill with marsh vegetation. New vegetation was also planted along the shore. At low water levels, the marsh may be above the water line and the sill is emergent. *Michigan Department of Environment, Great Lakes, and Energy*

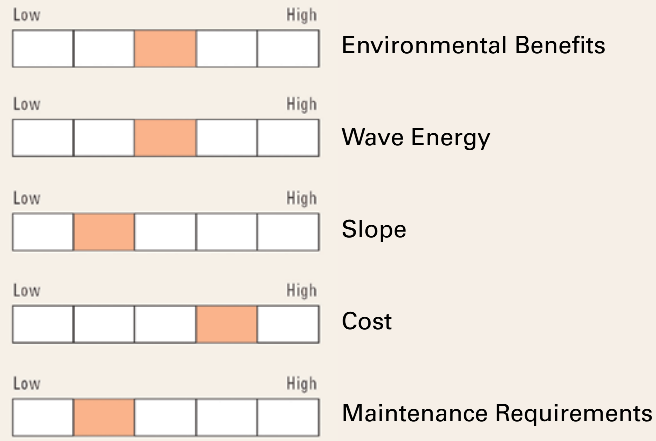
Overview

The city of Marysville replaced 1,885 feet of seawall on the St. Clair River with a marsh sill to combat the loss of fish and wildlife habitat in the river. Prior to construction, the shoreline consisted of a failing seawall of steel sheet pile and rock with a mowed turf grass lawn at the top. The shoreline experiences moderate wave energy from large ship wakes due to its location on the shipping lane between Lake Erie and Lake Huron. The project was funded by the Great Lakes Restoration Initiative and the city of Marysville in association with the St. Clair River Area of Concern. The project cost was $1.8 million (2012 cost), which included removing the existing seawall, constructing the marsh sill and making boardwalk improvements.

Design

The living shoreline consists of a rock sill, native vegetation and rock toe edging at the shore. The top of the sill is 2 to 3 feet below the ordinary high water mark. The stone edging is located on the shore at the ordinary high water mark. The sill reduces wave energy at the shore while the marsh vegetation and stone edging protects the shore from the remaining wave energy. At low water levels, the marsh may be above the water line and the sill is emergent. At high water levels, the sill and marsh may be completely submerged. Another part of the shoreline consists of a rock revetment where vegetation and shallow water habitats were also restored. Gravel, cobble and root wads, which are dead tree trunks with their roots attached, were placed offshore to provide shallow water habitat and spawning ground. Planting was done with seed, plant plugs and live stakes, which are cuttings from tree branches.

After – High Water At high water levels the marsh may be completely submerged. In this case the sill will dissipate some wave energy and stone edging will provide protection to the shoreline. *Michigan Department of Environment, Great Lakes, and Energy*



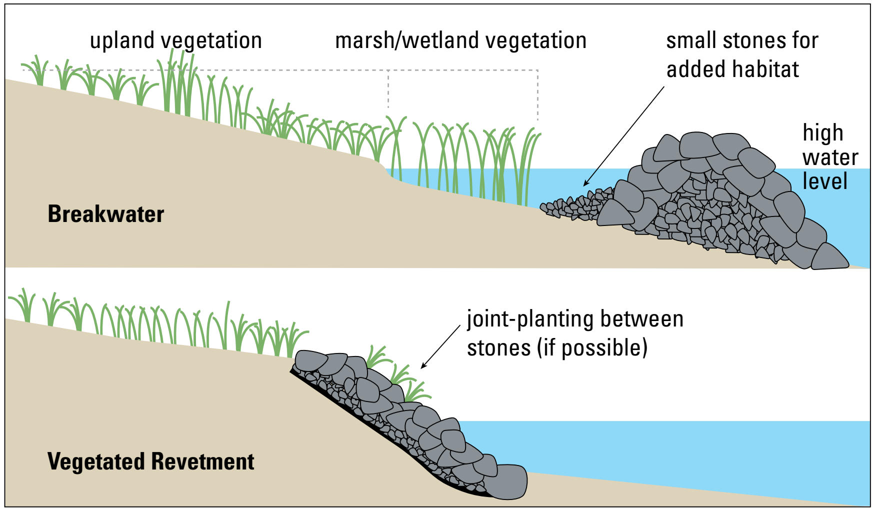
Results

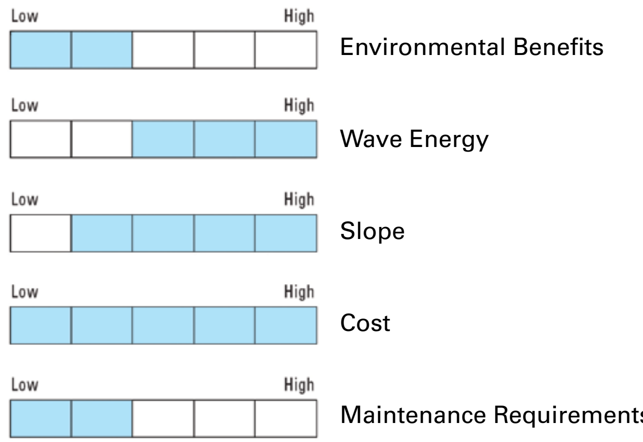
For two years following the project, invasive species were treated and have returned periodically. Weeding and general clean-up is done on the shore by volunteers each spring. Vegetation is thick and the structure has little to no erosion damage. When water levels are high, the sill is completely submerged and the area of submerged wetlands is larger, changing the look of the shoreline. Fish abundance was shown to increase after construction in an underwater habitat review, including the sighting of endangered fish species returning.

Lessons Learned | Marysville Shoreline

Because of water level fluctuation in the Great Lakes, the wetland is often completely submerged. The shoreline has held up very well against erosion during these periods of high water.

ECOLOGICALLY ENHANCED HARD ARMORING





Overview

In high wave energy environments, hard armoring like seawalls, breakwaters or revetments may be necessary to reduce erosion and flooding. However, there are several ways to enhance hardened coastal infrastructures to add some ecological benefits and/or lessen their impact on the environment.

Breakwaters, which are large structures of stone placed offshore, reduce wave energy at the shore, which can allow for naturalized beaches, vegetated shorelines or wetlands to establish where they might not otherwise exist along high wave energy coasts. Submerged reef breakwaters can also provide aquatic habitat for fish.

Revetments, which are shore parallel structures of erosion-resistant stone, can have vegetation incorporated between the stones, called a joint-planted revetment, or in the upland area to improve terrestrial and aquatic habitat compared to an unvegetated upland.

Modifying coastal structures with textured surfaces or additional smaller cobble stones can provide surfaces for aquatic species habitat that are unavailable on large armor stones, sheet pile or smooth concrete blocks.

Benefits

- A low-cost way to enhance an existing hard shoreline project with vegetation or textured surfaces
- Improves ecosystems of armored shorelines
- Improves visual appeal of armored shorelines

Challenges

- May disrupt natural coastal processes and accelerate erosion of adjacent properties
- May be a barrier for access to the shoreline for wildlife
- Can require more complicated design and construction than for a standard hard structure

Terrestrial vegetation growing adjacent to revetments. At armored coasts in Lake Erie, fish species richness was observed to be higher at sites with terrestrial vegetation than at non-vegetated sites (Simonson, 2017). *Adam Bechle*

Maintenance

Hard armor structures should be inspected for signs of damage routinely, at least once per year, and repaired as needed. Vegetation may need to be maintained with occasional replanting, weeding and invasive species control.

Resources

Engineering with Nature (EWN)

The goal of this USACE initiative is to align nature and engineering to provide economic, environmental and social benefits. Their website features ongoing projects, atlases of case studies, tools and a number of USACE publications.

ewn.el.erdc.dren.mil

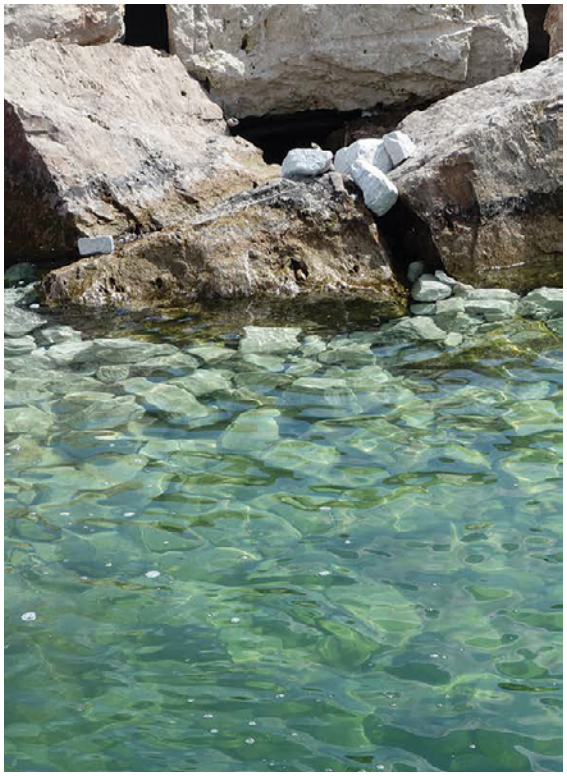
Sustainable Coastal Design and Planning – The Hard Habitats of Coastal Armoring

This book chapter, written by Richard Hindle, provides background on the novel ecology of hard armor materials and summarizes several examples of ecologically enhanced hard armoring.

escholarship.org/uc/item/1hs0d1hv

Related Options

Sills may be used in lower wave energy environments.



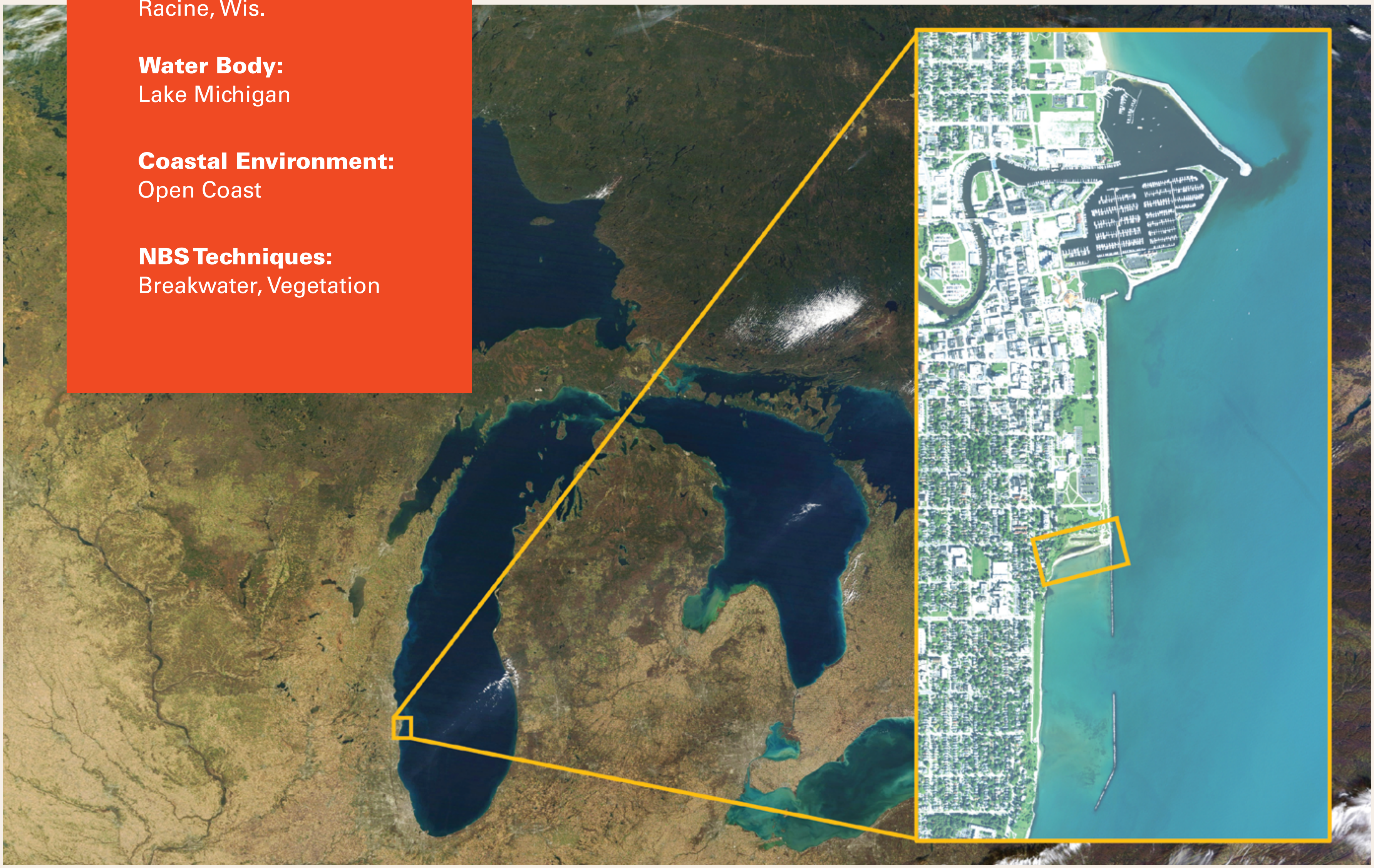
The USACE modified a section of the Milwaukee Harbor breakwater with a shallow slope of cobblestones to increase availability of fish habitat. *Burton Suedel*

Location:
Racine, Wis.

Water Body:
Lake Michigan

Coastal Environment:
Open Coast

NBS Techniques:
Breakwater, Vegetation



Case Study: Samuel Myers Park

Before Prior to the project, the area adjacent to the breakwater was eroded due to overtopping and the rest of the park was dominated by invasive Phragmites. *USACE*

After The raised breakwater facilitated construction of connected wetland areas. Invasive species were replaced with diverse native vegetation. An overflow channel was built adjacent to the breakwater to handle extreme storm surge and precipitation events. *Capt. Dennis Carr*

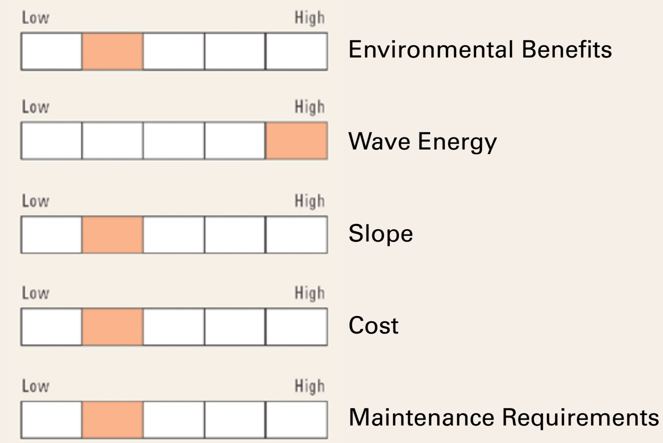
Overview

The Racine Public Health Department improved surface water quality at Samuel Myers Park by raising an existing breakwater, which allowed an existing native wetland to be restored and multiple green infrastructure components to be installed. Before the project, waves routinely overtopped the breakwater, causing erosion that formed a channel of stagnant water. Untreated runoff from the upland area of the park also contributed to the poor water quality. Vegetation at the beach was also confined to invasive species, primarily Phragmites. Raising the breakwater provided a protected area for the wetland restoration along this stretch of high wave energy open coast. The city received funding from 23 sources for this project, including the U.S. EPA Great Lakes Restoration Initiative, Wisconsin Coastal Management Program, Fund for Lake Michigan, U.S. Forest Service, U.S. Fish & Wildlife Service and the Root-Pike Watershed Initiative Network. The cost of raising the breakwater was $41,000 (~$205 per lineal foot), though salvaging limestone riprap from a legacy revetment on site reduced material costs significantly.

Design

The breakwater was raised by 3 to 4 feet to prevent overtopping from waves. This reduced erosion of the adjacent shore, allowing the existing wetland area to be protected and incorporated into a larger constructed wetland. Invasive species were removed and the constructed wetland and wetland fringe area were revegetated with native species. Dunes were also built to help capture runoff. In the upland area of the park, a rain garden and bioswale were built to help capture runoff and increase infiltration. Native vegetation was planted throughout the park, creating a diversity of habitat types including sand prairie, dune and wetland. The design has been adapted over time to help control large storm surges and excess runoff from significant precipitation events. This has included connecting the constructed wetlands with a drainage system, installing flow dissipaters to reduce runoff intensity and building an overflow drainage channel along the breakwater.

An area of established wetland near the breakwater. *Julie Kinzelman*



Lessons Learned | Samuel Myers Park

Racine's project leader learned that even well-researched design plans may not account for all site conditions, including those associated with lake level rise and climate change. Monitoring resulted in several amendments to the project, including the drainage system and flow dissipaters to better manage large storm events.

Results

After the project was completed, recreational water quality improved and an offshore swimming area was opened to the public. The native vegetation has established well, and several species of mammals, reptiles, amphibians and birds have returned to the area. Notably, Samuel Myers Park has been designated as a monarch waystation. Maintenance of the park includes weekly surface and groundwater monitoring within the wetland and nearshore areas (May – September), plant community surveys, invasive species control and upkeep of site amenities (April – November). City staff clean up and weed the site routinely, occasionally conducting volunteer events to assist with this effort.

GLOSSARY

Coastal Features

Bank A soil slope rising less than 10 feet above the beach.

Beach Zone of loose sediment between the shoreline and a line of permanent vegetation or a change in sediment.

Bluff A soil slope rising 10 feet or more above the beach.

Dune Ridge of loose, wind-blown sand.

Face The sloping section of a dune, bank, bluff or coastal structure.

Nearshore Zone of water between where waves begin breaking and the shoreline.

Offshore Zone of water lakeward from where wave breaking occurs.

Ordinary high water mark (OHWM) The point on the land where the lake leaves a distinct mark. The OHWM is usually indicated by physical characteristics like erosion or destruction of terrestrial vegetation. Some states use a set elevation for their OHWM.

Shoreline The point where the lake meets the land.

Toe The base of a dune, bank, bluff or coastal structure.

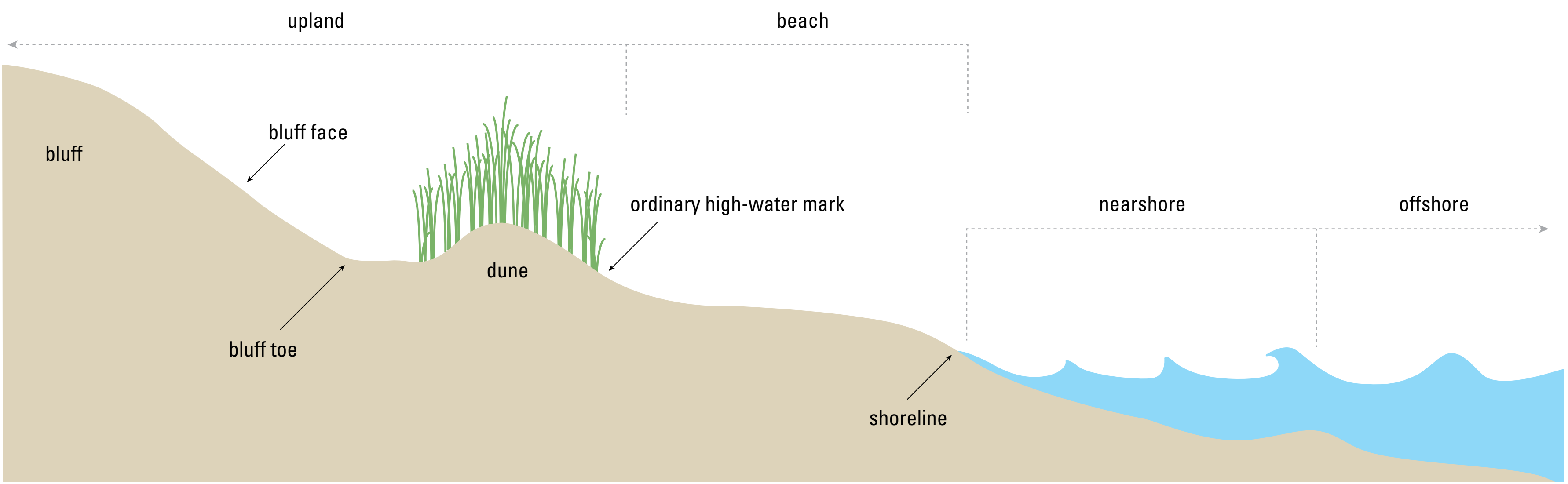
Upland Zone of land above the reach of waves and landward of the beach.

Coastal Processes

Sediment transport The movement of sediments, mostly sand and stones, in the nearshore area by waves and currents. Sediment is moved both perpendicular to the shore (cross-shore transport) and along the shore (alongshore transport). Sediment transport builds and maintains beaches. When sediment transport becomes interrupted it can lead to the loss of beaches.

Wave breaking The overturning of a wave, typically as the wave enters shallower water. This results in a reduction in wave energy and wave height.

Wave dissipation The loss of wave energy, often through wave breaking. It results in a decrease in wave height.



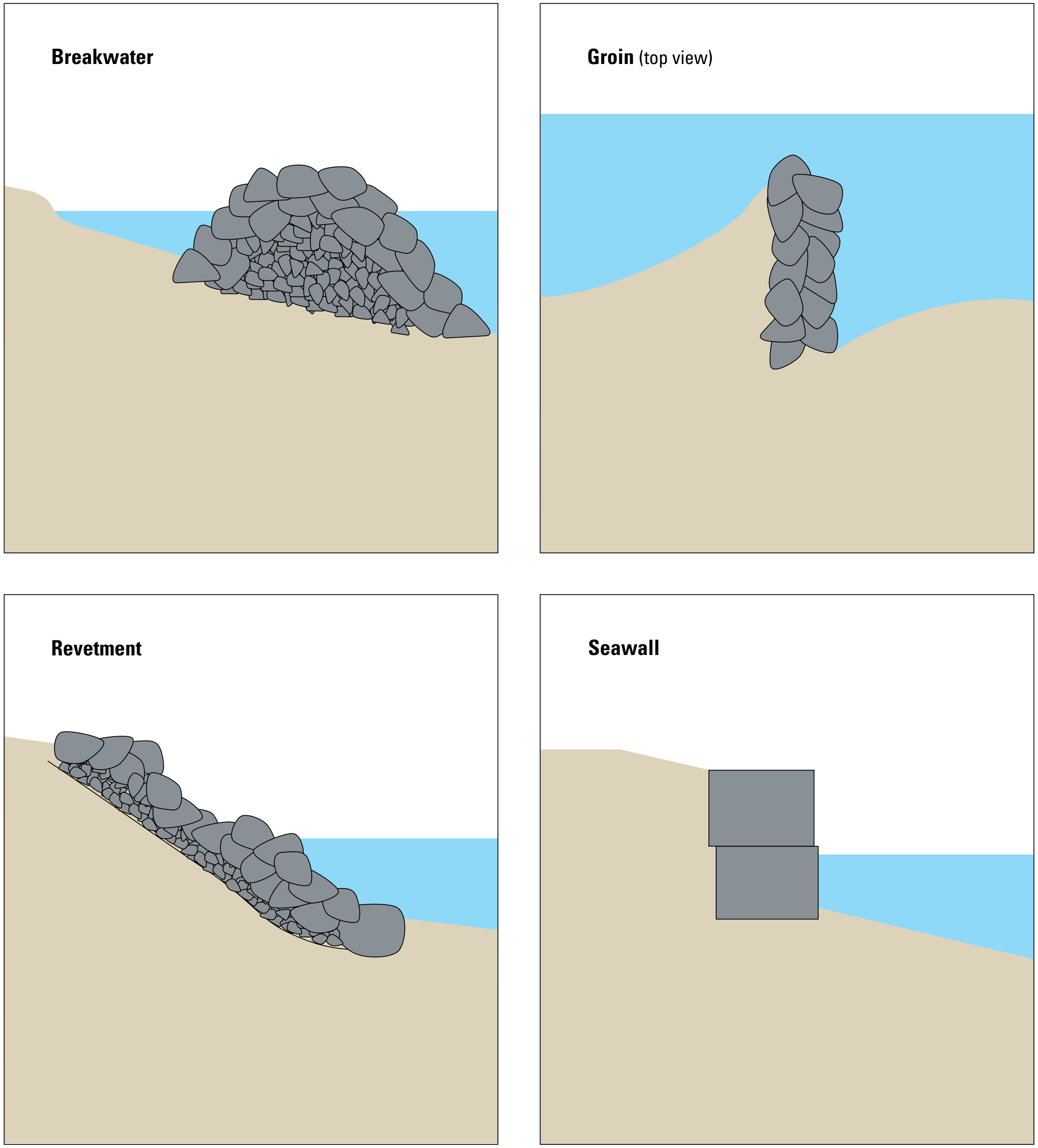
Hard Armoring

Breakwater - Stone or concrete structure built offshore to reduce wave energy at the coast.

Groin - Stone or concrete structure built perpendicular to the shore to trap sand and hold beach material in place.

Revetment - Interlocking pieces of stone or concrete on a gentle sloping face built to directly protect the shore from erosion.

Seawall - Vertical concrete or steel wall designed to protect the shore from erosion.



GREAT LAKES COASTAL RESOURCES

Nature-Based Shorelines Information

A Property Owner's Guide to Protecting Your Bluff
Wisconsin Sea Grant

Guide with considerations for managing and enhancing coastal bluff stability, including a list of plants suitable to Southeastern Wisconsin's Lake Michigan bluffs.
publications.aqua.wisc.edu/Bluffs

Nature-Based Shoreline Practices Workshop
New York Sea Grant

Video recordings of presentations on the possible uses of nature-based shorelines in the Great Lakes.
go.wisc.edu/1fa275

Using Natural Resilience Measures to Reduce Risk of Flooding and Erosion in New York State
New York State Department of Environmental Conservation

Overview of natural resilience measures to reduce risk of flooding and erosion along New York's marine and Great Lakes shorelines.
go.wisc.edu/j31lt7

Great Lakes Coastal Vegetation Selection Guidance

Working with Nature: A Guide to Native Plants for New York's Great Lakes Shorelines
New York Sea Grant

Guide on incorporating vegetation into a variety of Great Lakes shoreline types, including a list of plants suitable to New York's Great Lakes shorelines.
go.wisc.edu/9e8r50

Vegetative Best Management Practices: A Manual for Pennsylvania Lake Erie Bluff Landowners
Pennsylvania Coastal Zone Management Program

Guide with considerations for managing Lake Erie coastal bluffs, including a list of plants suitable to Pennsylvania's Lake Erie bluffs.
go.wisc.edu/3t6e23

Other Great Lakes Coastal Management Information

Living on the Coast
Wisconsin Sea Grant and United States Army Corps of Engineers

Booklet describing Great Lakes coastal processes and overall strategies to manage risk to coastal properties. It is a go-to resource for getting a broad understanding of the issues facing a property.
go.wisc.edu/474jz6

Adapting to a Changing Coast – Options and Resources for Lake Michigan Property Owners
Wisconsin Sea Grant

Publication with an overview of 16 management options for adapting to changing bluffs and beaches.
go.wisc.edu/53h2rx

Great Lakes Shore Protection Structures and Their Effects on Coastal Processes
Wisconsin Sea Grant

Detailed fact sheet describing different types of shore protection structures and their impacts, both positive and negative, on the shoreline.
go.wisc.edu/89c963

Stabilizing Coastal Slopes on the Great Lakes
Wisconsin Sea Grant

Detailed fact sheet describing the coastal conditions and processes that can lead to bluff failure and some options for stabilizing the slope of a coastal bluff.
go.wisc.edu/en3avy

Wisconsin Sea Grant Coastal Processes Manual
Wisconsin Sea Grant

Manual that provides instructions on how to estimate risk to Great Lakes coastal property from extreme lake levels, storms and erosion.
go.wisc.edu/619m7h

Ohio Coastal Design Manual
Ohio Department of Natural Resources

Manual that illustrates the engineering principles needed to develop successful erosion control and access projects along Ohio's Lake Erie shore, though practices are broadly applicable across the Great Lakes.
go.wisc.edu/9p5163

NATURE-BASED SHORELINES RESOURCE COLLECTIONS

Cold Regions Living Shorelines Community of Practice (CRLS CoP)
This community of practice focuses on communication, information sharing and knowledge-exchange to develop, support and steward the effective uses of living shoreline ideas and principles in a temperate North American climate. Their website features a library of resources, events calendar, recent news and a forum for discussion (registration required).
go.wisc.edu/q275qz

Engineering with Nature (EWN)
The goal of this United States Army Corps of Engineers Initiative is to align nature and engineering to provide economic, environmental and social benefits. Their website features a list of projects and a variety of literature.
go.wisc.edu/gt5m3q

Hudson River Sustainable Shorelines
A project focused on providing science-based information on shoreline management options that preserve natural function in New York's Hudson River Estuary, led by the Hudson River National Estuarine Research Reserve. The webpage has resources on design considerations, the performance of living shorelines in storms, case studies, outreach materials and other resources.
go.wisc.edu/1ny41p

NOAA Digital Coast Topic: Natural Infrastructure
Directory of National Oceanic and Atmospheric Administration (NOAA) guidance, data, tools, trainings and webinars on natural and nature-based solutions for minimizing coastal flooding, erosion and runoff. A specific resource of interest is the "Quick Reference on Nature Based Solutions."
go.wisc.edu/hp7930

NOAA Living Shorelines Website
National Oceanic and Atmospheric Administration (NOAA) webpage on living shorelines, including a map of NOAA-supported living shorelines projects.
go.wisc.edu/nvs66c

Living Shorelines Academy
Put together by the North Carolina Coastal Federation and Restore America's Estuaries, this site provides online courses in living shorelines for property owners and professionals. It also features a comprehensive list of living shorelines resources, projects and professionals.
livingshorelinesacademy.org

Naturally Resilient Communities
The website of this partnership provides information on using nature-based solutions to protect against flooding and erosion. They feature solutions and case studies for different hazards, regions and scales.
nrcsolutions.org

The Nature Conservancy's Coastal Resilience Program
This is a program led by The Nature Conservancy to examine nature's role in reducing coastal flood risk. The program consists of an approach, a web mapping tool and a network of practitioners around the world supporting hazard mitigation and climate adaptation planning.
coastalresilience.org

Systems Approach to Geomorphic Engineering (SAGE)
This community of practice focuses on promoting the use of green and gray integrated solutions for coastal resilience across many coastal regions. Their website features a project database, a list of resources for technical guidance and more.
sagecoast.org

Virginia Institute of Marine Science (VIMS) Living Shorelines Webpage
Website with descriptions of living shoreline practices, examples of living shorelines in Virginia, design guidance and a site suitability tool for selecting living shorelines on Virginia coasts.
go.wisc.edu/nuh65m

OTHER NATURE-BASED SHORELINES RESOURCES

Design Guidance

Bilkovic, D.M., M.M. Mitchell, M.K. La Peyre, and J.D. Toft, 2017. ***Living Shorelines: The Science and Management of Nature-Based Coastal Protection.*** CRC Press.

Hardaway, Jr., C.S., D.A. Milligan, K. Duhring, K., and C.A. Wilcox, 2017. ***Living shoreline design guidelines for shore protection in Virginia's estuarine environment (Special Report in Applied Marine Science and Ocean Engineering #463).*** Gloucester Point, VA: Virginia Institute of Marine Science.
doi.org/10.21220/V5CF1N

Johannessen, J, A. MacLennan, A. Blue, J. Waggoner, S. Williams, W. Gerstel, R. Barnard, R. Carman, and H. Shipman, 2014. ***Marine Shoreline Design Guidelines.*** Washington Department of Fish and Wildlife, Olympia, Washington.
go.wisc.edu/qlbs0q

Miller, J.K, A. Rella, A. Williams, and E. Sproule, 2015. ***Living Shorelines Engineering Guidelines.*** New Jersey Department of Environmental Protection.
go.wisc.edu/25q51x

Webb, B., B. Dix, S. Douglass, S. Asam, C. Cherry and B. Buhring, 2019, ***Nature-Based Solutions for Coastal Highway Resilience: An Implementation Guide.*** US Department of Transportation Federal Highway Administration.
go.wisc.edu/z26nb8

Monitoring Guidance

Science and Resilience Institute at Jamaica Bay, 2018. ***Measuring Success: Monitoring Natural and Nature-Based Shoreline Features in New York State.*** Report prepared by the Science and Resilience Institute at Jamaica Bay.
go.wisc.edu/74mgz0

Yepsen, M., J. Moody, and E. Schuster, 2016. ***A Framework for Developing Monitoring Plans for Coastal Wetland Restoration and Living Shoreline Projects in New Jersey.*** Report prepared by the New Jersey Measures and Monitoring Workgroup of the NJ Resilient Coastlines Initiative.
go.wisc.edu/04qchk

Case Studies and Examples

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