

NEW YORK STATE | Department of Environmental Conservation | Department of State

Using Natural Measures to Reduce the Risk of Flooding and Erosion

Guidance From New York State's Department of Environmental Conservation and Department of State

AUGUST 2020

Andrew M. Cuomo, Governor | Basil Seggos, Commissioner | Rossana Rosado, Secretary of State

Acknowledgments

This report was prepared by the Natural Resiliency Measures Drafting Team, pursuant to the New York State Community Risk and Resiliency Act. The core planning team consisted of Kristin Marcell, Carolyn Fraioli, Emilie Hauser, Stephanie Wojtowicz, Shannon Dougherty, Betsy Blair, Jeffrey Mapes, Francis Sheehan, Karen Strong and Barry Pendergrass. The internal drafting and review teams included many staff from the New York State Departments of Environmental Conservation, State, Transportation and Agriculture and Markets, the New York State Environmental Facilities Corporation and Office of Parks Recreation and Historic Preservation. The New York State Energy Research and Development Authority provided funding for editorial assistance from the Eastern Research Group. Organization and assistance for graphic design was provided by Steve Stanne, Lucy Potter, Sarah Lipuma and the NYS DEC Office of Communication Services.

We would like to thank the following external reviewers who reviewed early drafts of the feature descriptions and/or the guidance:

- Marit Larson, New York City Parks
- Jon Miller, Stevens Institute of Technology
- Philip Orton, Stevens Institute of Technology
- Peter Weppler, United States Army Corps of Engineers
- Jay Tanski, New York Sea Grant
- Heather Weitzner, O'Brien and Gere
- Henry Bokuniewicz, SUNY SoMAS
- Werner Mueller, HDR
- Rick Gilbert, Blue Shore Engineering
- Nava Tabak, Scenic Hudson
- Beth Reichheld, New York City Department of Environmental Protection
- Todd Walter, Cornell University
- Wendy Walsh, Tioga County Soil and Water Conservation District
- Jessica Ottney, The Nature Conservancy
- Pippa Brashear, SCAPE Landscape Architecture
- Novem Auyeung, New York City Parks

Funding for facilitation support by the Consensus Building Institute was provided by a grant from the National Estuarine Research Reserve System Science Collaborative, which supports collaborative research that addresses coastal management problems important to the reserves. The Science Collaborative is funded by the National Oceanic and Atmospheric Administration and managed by the University of Michigan Water Center.

NATIONAL ESTUARINE RESEARCH RESERVE SYSTEM SCIENCE COLLABORATIVE

Suggested Citation: New York State Department of Environmental Conservation. (2019). Using Natural Resilience Measures to Reduce Risk of Flooding and Erosion in New York State.

Contents

Figures

Tables

Appendices

Appendices – List of Figures

Acronyms

CRRA	Community Risk and Resiliency Act
DAM	New York State Department of Agriculture and Markets
DEC	New York State Department of Environmental Conservation
DOH	New York State Department of Health
DOS	New York State Department of State
DOT	New York State Department of Transportation
ECL	Environmental Conservation Law
EFC	New York State Environmental Facilities Corporation
EPA	United States Environmental Protection Agency
FEMA	Federal Emergency Management Agency
MHW	Mean High Water
NOAA	National Oceanic and Atmospheric Administration
NYCRR	New York Codes, Rules and Regulations
NYS	New York State
OPRHP	New York State Office of Parks, Recreation and Historic Preservation
USACE	United States Army Corps of Engineers

Executive Summary

The New York Department of Environmental Conservation (DEC) and Department of State (DOS) are pleased to present this overview of natural resilience measures and how they can reduce risk of flooding and erosion. Natural resilience measures are actions to conserve, restore or mimic natural landforms and processes that reduce risk from flooding and erosion. These measures also provide a variety of other public benefits. The use of natural resilience measures to reduce these risks is imperative to protecting our state's communities and environment. New York has made reducing these risks a priority for the state.

Examples of actions that support use of natural resilience measures to reduce risk:

- Provide pathways for natural protective features, like barrier islands, dunes and tidal wetlands, to migrate inland with sea-level rise. These features attenuate waves and surge, and tidal wetlands slow and store floodwaters. If they cannot migrate inland as water levels rise they may disappear.
- Create space for wetlands and floodplains. Do not fill them in. They slow, store and absorb floodwater and decrease the risk of stream, river and coastal flooding.
- Leave trees and other native vegetation in place, wherever possible, and especially on and near the shore and in the water. Their roots are very effective at holding sediment in place and reduce the energy of waves, surge and floodwaters.
- Set development well back from dunes, bluffs, inlets, beaches, wetlands, streams, riparian areas and floodplains. These features move and change as they absorb energy from strong storms. Development in or near them can create pathways for water to damage homes and other structures.
- Allow sediment to move along and across shorelines. Sediment movement downstream and along and across coastal shorelines is necessary to build and sustain features like beaches, dunes, shoals, tidal wetlands and barrier islands that reduce risk.
- Always consider nature-based features where adjustments to land use or conservation and restoration of natural features alone are not feasible or sufficient to reduce risk.

The Community Risk and Resiliency Act (CRRA) requires state agencies and applicants to consider future physical climate risks, including storm surge, sea-level rise and flooding and extreme weather events in certain permitting, funding and regulatory actions. It also calls for DEC and DOS to develop guidance in accordance with CRRA requirements. This includes a specific requirement to develop guidance on how natural resilience measures can be used to reduce risks from storm surge, sea-level rise and flooding.[1] This document provides an

[1] DEC and DOS interpret this to include erosion, which contributes to and is a result of flood risk.

overview of natural resilience measures and will be used to support the future development of program-specific guidance for state regulatory programs covered by CRRA.

This document does the following:

- Describes natural resilience measures and how they can be used to mitigate the risks of flooding and erosion
- Provides definitions for different types of natural resilience measures and distinguishes among conserved, restored, nature-based and hard structural approaches
- Provides information on the value and benefits of using natural resilience measures, along with information on the co-benefits they provide
- Lists key factors to consider in the restoration, design and construction of natural resilience measures
- Provides background to support the development of state agency guidance on natural resilience measures in the future.

This guidance does NOT do the following:

- Specify which natural resilience measures should be used in specific locations
- Provide detailed or site-specific engineering design and construction guidance for the restoration of natural features or the design and construction of nature-based features

This report recognizes that there are cases where natural resiliency measures cannot adequately address concerns for safety, loss of life or the protection of significant public infrastructure. In these cases, there may be opportunities to include components that enhance their ecological value or public co-benefits in the design.

Key Findings

Below are key findings on climate change, flood and erosion risk in New York State, and the use of natural resilience measures (natural and nature-based features) to reduce this risk. These findings are the basis for this guidance.

- Sea-level rise and intense storms present risks to life, property and assets in NYS from storm surge, wind-driven waves, flooding and erosion. These risks will increase over time as the climate continues to change. NYS must manage its vulnerability to these risks.
- Federal and state policies recognize that measures that incorporate natural features and processes can reduce risk to life, property and assets and provide large-scale environmental co-benefits, like water filtration, food production and carbon storage.
- Natural features and natural processes are not static, but parts of systems that move and change in response to human and natural disturbance. Over time, the cumulative effects of many small disturbances can result in large-scale changes in natural systems; large storm events can have sudden dramatic effects.
- Siting development near or within natural features that can move or change in response to flooding, such as coastal bluffs and stream corridors, increases risk to human assets and decreases the ability of natural features to reduce risk at a larger scale (e.g., community, shore zone and watershed).
- Adequate buffers, which may be greater than the limits of regulatory jurisdiction, between development and natural features improve the ability of natural features to respond to natural and human disturbance, which helps to maintain their valuable functions, including risk reduction.
- Intact and restored natural features and processes are more beneficial than constructed nature-based features because of the potentially greater range and scale of environmental co-benefits they provide and the greater likelihood of successful integration with larger-scale natural systems.
- Erosion-prevention, flood-mitigation and stormwater-management measures that conserve, restore or mimic the ability of natural features and processes to reduce risk, have fewer impacts on surrounding areas and provide more environmental co-benefits than hard structural measures.
- Erosion-prevention, flood-mitigation and stormwater-management measures that conserve, restore or mimic the ability of natural features and processes to reduce risk may require more frequent maintenance initially to manage vegetation, but these measures are adaptable over time and their costs are favorable when compared with hard structural measures over a project lifespan.
- Structural erosion-management, flood-mitigation and stormwater-management strategies that do not rely on or mimic natural systems are often only partially effective

over time, may be harmful to adjacent or nearby properties and can compromise the function of natural features and processes that reduce risk.

- Structural erosion-prevention and flood-mitigation strategies may be necessary in some locations to provide water-dependent uses or where existing development or critical infrastructure cannot otherwise be adequately protected.
- No single measure or feature can eliminate all risk. Redundancy, or the use of more than one strategy to manage risk, is more effective than any single strategy alone.
- The success of a natural or nature-based feature depends on adequate consideration of both the current and future physical forces and the condition of natural features and processes at the site and the feature's ability to move, migrate, reestablish or otherwise adapt or be adapted in response to natural processes, extreme weather events and sea-level rise.

1. How to Use This Document

This guidance provides information to help decision makers better understand natural resilience measures and how they can help to reduce risk from sea-level rise, storm surge, flooding, erosion and extreme weather events.

Section 2. *The Policy Context for Promoting Natural Resilience Measures* provides background and context to support consideration of natural resilience measures to reduce risk of flooding and erosion and describes why their use is a priority for New York.

Section 3. *Understanding Natural Resilience Measures* provides a basic understanding of natural resilience measures including the following:

- Key terms such as natural resilience measures, natural and nature-based features, non-structural measures and hard structural measures
- Examples of natural resilience measures that are being used in New York today
- Considerations for the management of risk and threats to natural resilience measures

Section 4. *Natural and Nature-based Features That Reduce Risk of Flooding and Erosion* provides definitions of 20 natural and nature-based features that can reduce risks to people and communities and how they reduce risk.

1.1 Appendices

Appendix A provides detailed information, based on literature and expert review, on 20 natural and nature-based features that can reduce risks to people and communities and provide public co-benefits including the following:

- Definitions and descriptions of each feature, which can be used to identify these natural features on a site
- How the feature reduces risk
- Human activities that can reduce or impair the risk reduction capacity of the feature
- Possible effects of changes in climate and water level on the feature
- Public co-benefits of each natural feature
- Examples of where the feature has been implemented
- Design, construction and maintenance considerations specific to that feature

Appendices B-F summarize important information on natural processes that support natural features, public co-benefits of natural features, how costs of nature-based and hard structural features compare, the negative effects of hard structural features, where hard structural features are appropriate and considerations for natural features in a changing environment.

This guidance incorporates the findings of the CRRA State Flood Risk Management Guidance and provides the foundation for, or informs, several additional guidance documents that DEC and DOS will produce as part of CRRA implementation. It will be used to support the development of program-specific guidance for several state regulatory programs.

2. The Policy Context for Promoting Natural Resilience Measures

2.1 Flood Risk is Increasing

The consequences of flooding and erosion are expensive and the frequency of extreme flood events is increasing. The 2014 State Hazard Mitigation Plan identifies flooding, hurricanes and coastal storms as the cause of over half of all natural hazard-related economic damages in New York (NYS DHSES, 2014).

Sea-level rise and changes in storm intensity are increasing the frequency, severity and extent of flood damages (Horton et al., 2014; NYS DEC, 2015). Sea-level is projected to rise up to six feet, and possibly more, by 2100 (6 NYCRR 490.4; Sweet et al., 2017). The continuing population migration towards waterfront communities further contributes to the vulnerability of lives and assets (NOAA OCM and U.S. Census, 2013). A report on climate adaptation funded by NYS in 2011 estimated that, without adaptation, the impacts of climate change in NYS, including coastal storms and flood events, could be as much as $10 billion annually by mid-century, with insured losses in ocean coastal zones alone estimated to reach $44-77 million annually by mid-century (Rosenzweig et al., 2011).

The current federal National Flood Insurance Program (NFIP), New York State Fire Prevention and Building Code,[2] state permit regulations, and infrastructure design requirements include some provisions for keeping water away from vulnerable structural components and critical systems, however, the regulations associated with these programs do not consider risks associated with sea-level rise and stronger storms. They also offer limited to no guidance on how to use natural and nature-based features to reduce risk.

Natural features such as dunes, wetlands and floodplains are often lost a little at a time in individual development decisions. For example, nearly two-thirds of coastal wetlands in the NY-NJ-CT region have been filled in since the nineteenth century. (Regional Plan Association, 2018) The cumulative impact of individual decisions to fill wetlands and floodplains, dredge streams and straighten or harden shorelines has increased flood and erosion risk in many developed areas. These losses mean that each natural feature that is conserved or restored has an even more important role in reducing flood and erosion risk. Information on natural features and processes that reduce risk is needed to ensure that the protective value and management of natural features and processes are not overlooked in local land use planning. This document begins to address this need.[3]

[2] Residential and non-residential code requirements are available through the Department of State at http://www.dos.ny.gov/dcea/.

[3] See Appendices A and B for more detailed information on natural features and processes that reduce risk.

2.2 State and Federal Policies Recognize the Value of Natural Resilience Measures

In the 1970s, both the federal government and New York State began to officially recognize the value of natural features and processes in policy. The federal government enacted a variety of environmental policy changes. These included consideration of the value of floodplains in federally-funded projects.[4] In NYS, over several decades, new environmental laws were passed and regulations promulgated to identify and conserve stream and river banks, tidal wetlands, freshwater wetlands and coastal natural features, including beaches, bluffs and nearshore areas. For example, the Tidal Wetlands Land Use Regulations promulgated to implement the Tidal Wetlands Act, passed in 1973, state the following:

> "It is the purpose of this Part to implement that policy by establishing regulations that allow only those uses of tidal wetlands and areas adjacent thereto that are compatible with the preservation, protection and enhancement of the present and potential values of tidal wetlands (including but not limited to their value for marine food production, wildlife habitat, *flood and hurricane and storm control (emphasis added)*, recreation, cleansing ecosystems, absorption of silt and organic material, education and research, and open space and aesthetic appreciation), that will protect the public health and welfare, and that will be consistent with the reasonable economic and social development of the State" (6 NYCRR 661).

Similar language, recognizing the value of natural resilience measures to reduce risk of flooding and strong storms can be found in implementing regulations for Article 24 (Freshwater Wetlands). DEC guidance for Article 15 (Protection of Waters) recognizes that hard structural measures can increase the risk of erosion in stream and coastal areas and encourages the use of nature-based features (NYS DEC, n.d.). In addition, the regulations and guidance implementing Article 34, (Coastal Erosion Hazard Areas) recognize the value of natural protective features and assert that hard structural erosion management measures are "expensive, often only partially effective over time, and may even be harmful to adjacent or nearby properties" (6 NYCRR 505.9; 6 NYCRR 505.6).[5] In 2017, DEC released *Living Shorelines in the Marine District of New York State* to provide more detailed guidance and best management practices for the design, implementation and monitoring of nature-based features in marine coastal areas of New York State (NYS DEC, 2017).

[4] Exec. Order 11988, "Section 1. Each agency shall provide leadership and shall take action to reduce the risk of flood loss, to minimize the impact of floods on human safety, health and welfare, and to restore and preserve the natural and beneficial values served by floodplains in carrying out its responsibilities…" *https://www.archives.gov/federal-register/codification/executive-order/11988.html*

[5] For more information on how the costs of hard structural features compare to nature-based features and the effects of hard structural features see Appendices D and E.

The use of natural resilience measures in New York was outlined as a key response in the wake of Superstorm Sandy and tropical storms Irene and Lee. In 2012, Governor Cuomo appointed the NYS 2100 Commission to investigate how to make the state more resilient. Published in 2013, the *NYS 2100 Commission Report* specifically recommended protecting natural features as one of nine cross-cutting recommendations to reduce future risk. The report stated,

> "The Commission recommends that New York State adopt measures that promote the use of green and natural infrastructure through direct investment, new incentive programs and education. A [natural] infrastructure approach emphasizes the use of solutions that maintain and support services provided by natural systems, such as wetlands and dunes that can serve as natural buffers against storm surges and complement efforts to build new traditional infrastructure to protect communities." (NYS 2100 Commission, 2013)

The report recognized natural systems approaches as an important complement to structural solutions and identified ways that natural systems reduce risk. It also recommended changes to some state permitting programs to conserve natural features, like wetlands, that reduce risk.

Other state and federal programs support the use of natural resiliency measures:

- The guidance for New York Rising Community Reconstruction Plans strongly recommends protecting natural features to reduce risk (NYS, 2013).
- New York's Climate Smart Communities Certification Program outlines a framework for local governments to mitigate and adapt to climate change and funds and rewards implementation of natural resilience measures (NYS DEC, 2018).
- New York's Coastal Management Plan, administered by DOS, includes specific policies that call for the consideration of non-structural strategies and protection of natural protective features (NYS DOS, 2017).
- The USACE recently released a report on coastal resilience that creates a framework for evaluating and integrating natural and nature-based features with structural and non-structural measures (Bridges et al., 2015).
- The Federal Emergency Management Agency promotes natural resilience measures to mitigate hazards, such as protecting and enhancing riverbanks, wetlands, dunes and other natural features that mitigate flooding (FEMA, 2013).
- The National Oceanic and Atmospheric Association (NOAA) has developed planning and decision support tools to identify, map and conserve natural features in shoreline communities that are accessible through its Digital Coast Tool (NOAA OCM, n.d.).
- The Environmental Protection Agency (EPA) has long advocated for using natural and nature-based features to protect water quality. The agency is promoting the use of

nature-based features at various scales to manage the increased risk of inland and coastal flooding (EPA, n.d.-a).

State and federal support for natural resilience measures is clear; however, recent studies suggest more detailed guidance is needed to promote use of natural resilience measures, especially along shorelines in coastal areas (CGIES Task Force, 2015; ARCADIS, 2014; Livermont et al., 2014; Restore America's Estuaries, 2015). This guidance will help to meet that need.

2.3 The Community Risk and Resiliency Act Calls for Guidance on Natural Resilience Measures

In 2014, the New York State Legislature passed and Governor Andrew M. Cuomo signed into law the Community Risk and Resiliency Act (CRRA). This law requires state agencies and applicants to consider future physical climate risks, including storm surge, sea-level rise and flooding, and extreme weather events in certain permitting, funding and regulatory actions. It also asks these agencies and applicants to consider these risks in smart growth assessments, the siting of wastewater treatment plants and hazardous waste storage and disposal facilities, design and construction regulations for petroleum and chemical bulk storage facilities and oil and gas drilling permits, and properties listed in the state's Open Space Plan.

CRRA has several provisions. It calls for the following:

- DEC to adopt official projections of sea-level rise and update them every five years.[6]
- Applicants in several specified permitting and funding programs to demonstrate consideration of future risks from sea-level rise, storm surge and flooding, and for DEC to consider these risks in certain facility siting regulations.
- Adding mitigation of sea-level rise, storm surge and flooding to the list of criteria under the Smart Growth Public Infrastructure Policy Act, Environmental Conservation Law (ECL) Article 6.
- DOS and DEC to prepare guidance for communities on model local laws to manage physical climate risks.
- DEC and DOS to provide guidance to fulfill the requirements of CRRA, including guidance on the use of measures that use natural resources and natural processes to reduce risk.

The Climate Leadership and Community Protection Act (CLCPA), enacted in 2019, amended CRRA to expand the list of permits to which CRRA applies to include all permits covered by the Uniform Procedures Act. The CLCPA also expanded the list of hazards that must be considered to include all climate hazards, not only sea-level rise, storm surge and flooding. Finally, as amended, CRRA grants DEC statutory authority to require mitigation of risk to public

[6] Sea-level rise projections were adopted by NYS in February 2017 (6 NYCRR 490.4).

infrastructure and/or services, property not owned by the applicant, disadvantaged communities and natural resources.

By calling for guidance on the use of measures that use natural features and processes to reduce risk, CRRA explicitly recognizes that protecting and restoring natural features and promoting the use of nature-based features in state and local decisions will contribute to resilience and reduction of risk from flooding and erosion.

After CRRA was signed into law, DEC and DOS organized a technical workgroup that included staff from DEC, DOS, Office of Parks, Recreation and Historic Preservation (OPRHP) and State Department of Transportation (DOT) to draft this guidance on natural resilience measures.

The group defined natural resilience measures as actions that

- conserve natural features that reduce erosion and flood risk,
- restore natural features that reduce erosion and flood risk,
- construct nature-based features to mimic natural processes that reduce erosion and flood risk.

3. Understanding Natural Resilience Measures

3.1 What are Natural Resilience Measures?

Natural resilience measures are actions to conserve, restore or mimic natural landforms (or features) and natural processes that reduce risk from flooding and erosion. [7, 8]

Individual features are part of larger natural systems and are linked by natural processes. In every case, the larger natural system is an important component of the risk-reduction value of any feature.

Landforms that are created by physical, geological, biological and chemical processes that evolve over time through the forces of nature are known as *natural features*. Examples of natural features are wetlands, floodplains, dunes and barrier islands. Natural features can reduce the risk of flooding and erosion. Some act as barriers to resist the flow of water while others create friction to slow the flow of water, reducing its energy and power to cause damage. Other natural features store and/or absorb excess water, stabilize the movement of sediment, supply sediment to other features and facilitate or enhance the drainage of water.

Natural features also provide other benefits, or co-benefits, to society, including cleaning our water and air, mitigating drought, sequestering carbon and providing or enhancing spaces for recreation. [9]

Natural resilience measures are generally divided into two categories (Table 3-1):

- *natural feature conservation*, which includes non-structural measures
- Nature-based or soft structural measures (USACE, 2002)

Natural feature conservation is action to protect and manage natural features to reduce risk and conserve the benefits they provide for future generations. Conserving natural features is more efficient than trying to restore or

NYS Coastal Policies are explicit in their consideration of non-structural measures to reduce risk of flooding and erosion, whenever possible.

Environmental Conservation Law Article 34 (6 NYCRR Part 505), Article 25 Tidal Wetlands Act (6 NYCRR Part 661) and Article 24 Freshwater Wetlands Act (6 NYCRR part 663, Part 664, and Part 665) also favor their use by requiring setbacks from natural features that reduce risk.

[7] Definitions of natural feature and nature-based features are adapted from USACE (2015).

[8] The following definitions generally comply with federal water resource agencies (e.g., USACE and EPA) and with state policies of DEC and DOS including New York State's Coastal Management Program. *USACE, DEC, and DOS may each use slightly different definitions for certain terms. Please consult with the respective agency for more information.*

[9] For more information on the co-benefits of natural and nature-based features see Appendix C.

recreate them, which can be technically challenging and expensive.

Non-structural measures can be used to conserve natural features that reduce risk. These actions do not involve the direct management of water flows, but instead manage flooding and erosion by moving assets out of areas at risk or preventing siting of new structures in these areas. (Figure 3-1). They include elevating or relocating assets out of vulnerable areas, setbacks to prevent the siting of new structures in vulnerable areas and adapting structures so they are not harmed during flood events. They are effective at reducing both short- and long-term flood damage and are cost effective over the long term when compared to other management techniques (USACE, 2016).

Credit: NYS DEC.

Figure 3-1. Home elevation is a non-structural measure to reduce risk.

Nature-based or soft structural measures are actions to enhance or mimic characteristics of natural features and processes by restoring natural features or constructing nature-based features. These features typically provide additional co-benefits like improving water quality or habitat.

- ***Natural feature restoration*** is action taken to re-establish natural features and processes that have been degraded or altered to enhance the natural risk-reduction capacity of the feature while supporting the native ecological systems. Restoration often aims for minimal or short-term disturbance. It may include short-term components to stabilize features and establish vegetation. It also may involve removal of structural barriers, excavation, fill, re-vegetation or other restorative measures, depending on how the natural system has been degraded. Restoration should be based on features or systems that historically existed at the site or in the vicinity, and emulate pre-development conditions (Figure 3-2).

- ***Nature-based feature construction*** is action to create features that mimic natural features and processes. To reduce risk these features are designed to function with and accommodate natural processes and provide specific services, such as resisting erosion or enhancing stormwater management. Nature-based features are preferred at sites where natural features alone will not sufficiently reduce risk.

Nature-based features typically incorporate or promote the growth of living materials (e.g., vegetation or shellfish) and limit disturbance to existing habitat. Based on a number of factors, including site conditions, nature-based features may include structural components. However, they should use the minimum amount of structural components necessary to achieve project goals, while also realizing habitat and resilience benefits. Nature-based features may also require some excavation and/or fill.

Credit: NYS ACE

Figure 3-2. At the Tifft Nature Preserve in Buffalo, NY, wetland habitat improvements included control of the invasive species, *Phragmites australis* (common reed) and planting of emergent native vegetation to restore wetland habitat at a former shipyard.

Nature-based features range from those that consist of primarily natural material and provide higher ecological value, sometimes referred to as “greener,” to those that consist of more structural material and provide lower ecological value, sometimes referred to as “grayer.”

For example, shoreline strategies on the greener end of the spectrum might use natural substrate and native vegetation, offer a wide sloping shore or riparian zone and emulate native habitat conditions. Strategies on the grayer end might result in more modified shorelines, a narrower shore zone and reduced natural processes.[10] Measures that are primarily hard structural are not considered nature-based features (Figure 3-3).

Credit: US ACE

Figure 3-3. Example of shoreline techniques from “green” to “gray.”

For shorelines and stream banks, nature-based features are sometimes referred to as “hybrid,” “living shorelines,” “bio-engineered,” or “bio-technical.” Nature-based features for stormwater management may be called “constructed stormwater green infrastructure” or “low impact development” methods.

Whether used along the coast, along streams and riverbanks, or elsewhere, nature-based features may be effective at mitigating various causes of flooding and erosion:

- Nature-based coastal techniques can be used along ocean, estuarine, bay, large river and lake shore zones that are subject to waves, wakes and surges perpendicular to the shoreline and currents parallel to the shoreline. Depending on location they may also be exposed to tides, sea-level rise and salt water.
- Nature-based stream and riverine techniques can be applied to smaller stream and riverine systems generally exposed to currents parallel to the shoreline.

[10] For more information on general principles to foster ecological benefits along shorelines see Strayer and Tumblety (2015).

- Constructed Stormwater Green Infrastructure can be used to slow and store water from precipitation or to convey meltwater moving downhill to another waterbody (Figure 3-4).

Restored and nature-based features should be monitored over their lifetime, but especially in the early stages. They usually require progressively less maintenance over time as they become established.

Descriptions of nature-based features that can be applied in coastal, stream and upland environments to reduce the risk of erosion and flooding can be found in the Feature Descriptions (Section 4 and Appendix A). Natural and nature-based features may require more frequent maintenance initially to manage vegetation, but these measures are adaptable over time and their costs are favorable when compared with hard structural measures over a project lifespan.[11] The effectiveness of these techniques depends on site and environmental conditions, project design and construction and proper and adaptive maintenance over time.

Credit: City of Philadelphia Water Department

Figure 3-4. Examples of constructed stormwater green infrastructure including from left to right, porous paving, stormwater bumpout, stormwater tree, stormwater planter, stormwater inlets, stormwater tree trench and rain garden.

[11] See Appendix D for more information on how the long-term costs and adaptability of nature-based features compare with hard structural features.

3.2 Hard Structural Measures

Hard structural measures are actions to construct hard structural features to control or direct water and/or sediment movement. Hard structural features can disrupt natural features and processes and have limited or no living components. While they can be necessary to protect critical infrastructure, and in some cases are the only alternatives, they can negatively affect natural features that reduce risk. Some examples include levees, bulkheads, seawalls, revetments, dams, structural stream channels and stormwater pipes and tunnels. Hard structural measures are not natural resilience measures. Features that have more hard structural components can be ecologically enhanced, to provide co-benefits, like habitat and water filtration, in areas where nature-based features alone won't sufficiently reduce risk.

Hard structural features commonly do not provide the environmental co-benefits provided by natural or nature-based features, such as water filtration, wave and surge buffering capacity, flood storage capacity, habitat and access to the water and can also compromise the ability of nearby natural features and processes to do so (Seitz et al., 2016; Duarte et al., 2013; NRC, 2014). Hard structures disrupt natural processes and may increase erosion in adjacent areas.

Hard structural features are typically strong immediately upon completion, but weaken with age. Eventually, all hard structural features will deteriorate, and they need periodic maintenance to continue providing protection. Still, hard structural features are necessary to protect some water dependent uses, assets such as roads and bridges and critical facilities and areas where natural or nature-based features will not provide the necessary level of protection. On public land they can provide some co-benefits such as access to fishing and recreation.[12] Features that have more hard structural components can also be ecologically enhanced, to provide co-benefits, like habitat and water filtration, in areas where nature-based features alone won't sufficiently reduce risk.

Any single feature can fail so using multiple features to reduce risk and provide redundant protection is advised, especially in high risk coastal areas exposed to multiple risks of flooding, erosion, sea-level rise, and extreme weather.

In sum, natural resilience measures (non-structural, soft structural) and hard structural measures comprise a range of strategies that help mitigate risk from flood and erosion. Specific measures, and their categorization, are presented in Table 3-1 below.

[12] See Appendix E for more information on hard structural measures.

Table 3-1. Examples of Flood and Erosion Risk Reduction Measures

Example Risk Scenario	NATURAL RESILIENCE MEASURES			Hard Structural Features
	Non-structural Measures	Soft Structural Measures		
	Natural Feature Conservation	Natural Feature Restoration	Nature-based Features	
Threat of flooding from a bay to assets in a waterfront public park	Acquisition of an adjacent wetland waterward of the park as open space	Restoration of a degraded wetland waterward of the park to reduce wave energy on the park	Installation of a low profile wetland sill made of bagged shell to reduce wetland erosion and reduce wave energy on the park	Construction of a bulkhead landward of the wetland along the shoreline of the park
Threat of storm surge to an oceanfront lighthouse	Relocation of the lighthouse further inland	Planting of dune grasses and shrubs to reduce wave energy on the shoreline of the lighthouse property	Creation of a new dune system with planted dune grasses to reduce wave energy on the shoreline of the lighthouse property	Construction of a seawall on the shoreline of the lighthouse property
Threat of flooding and erosion to a home in a floodplain	Elevation of the home above projected flood elevation (with no shoreline stabilization)	Reconnection of river to historic floodplain areas up-river to slow and store water and reduce flood elevations and energy downriver	Stabilization of streambank with stone and vegetation to reduce erosion	Channel straightening and hardening or damming (e.g., rip rap or concrete)
Threat of stormwater flooding and erosion from extreme precipitation in a suburban neighborhood	Local law that requires new development to conserve forests, wetlands and stream riparian areas	Replacement of undersized perched culverts with larger open box culverts to reduce stream constrictions; replanting of trees in stream corridors	Installation of rain gardens and bioswales to allow stormwater to infiltrate back in to the ground	Burying of streams in underground pipes

3.3 Understanding Limits of Risk Reduction Measures

All flood and erosion reduction measures have limits to their efficacy, which should be considered and understood.[13] Natural and nature-based features may prevent or minimize losses from costly chronic or low-level events, but size or capacity limitations may make them less effective in preventing damage from extreme precipitation, wide-spread flooding or surge from a major storm. That said, the risk-reduction capacity of nature-based features may increase over time. With regular maintenance, these features can become stronger as vegetation is established, sediment accumulates or shellfish reefs are colonized.

Hard structural measures are also limited in their ability to reduce risk from flooding and erosion. All hard structural measures deteriorate over time and require maintenance or replacement. When structural protection fails, protected community assets may be severely damaged and lives may be in jeopardy. In reviewing the effects of Hurricane Katrina, the National Academies stated "…because of the possibility of levee/floodwall overtopping-or more importantly, levee/floodwall failure-the risks of inundation and flooding never can be fully eliminated by protective structures no matter how large or sturdy those structures may be" (NAE and NRC, 2009).

In cases where natural resiliency measures cannot adequately address concerns for safety, loss of life or the protection of significant public infrastructure, hard structural measures may be appropriate and necessary. In such cases, a licensed professional trained in the design of these measures should select the appropriate measure. If hard structural measures are required there may be opportunities to include components that enhance their ecological value or public co-benefits in the design.

While necessary to protect some assets, such as roads, bridges and critical facilities, hard structural measures—as with any other—should not be used as a single management action because a single failure can have dire consequences. Using multiple measures to reduce risk (creating redundancy), especially in high risk coastal areas, is recommended, where practical (Figure 3-6). Relevant climate risks should be considered in the design of any risk management approach.

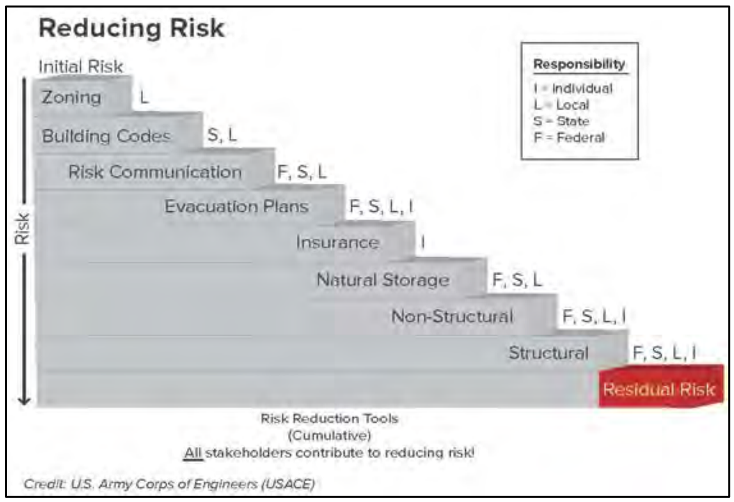
[13] Erosion, because it contributes to flood risk and is often exacerbated by flooding, is considered a significant hazard and widely referenced as simply "flooding and erosion."

The Constant Presence of Risk

Severe storm events are predicted to increase in New York because of climate change and sea-level rise will result in increased frequency of nuisance flooding along the ocean coast. The resulting damage from these effects will vary, ranging from chronic erosion and flooding from small, frequent storms or king tides to large severe storms that are rare or infrequent, yet when they occur can be catastrophic.[14]

A summer thunderstorm that drops two inches of rain or a king high tide that brings tidal waters higher and farther inland than normal may seem innocent enough, but damages can add up. The long-term, cumulative costs of chronic losses from minor storms and water level variation may exceed the damage from an infrequent but extreme storm.

However, we can all help to reduce these risks. Individuals can support local and state policies to discourage development in flood-prone areas and conserve natural features that reduce risk. Residents in high risk areas can purchase flood insurance, have an evacuation plan or pursue home elevation, relocation or buyouts (Figure 3-5). Land use planning and policies that direct development away from high-risk areas and limit loss of protective natural features are essential strategies for risk reduction.[15]



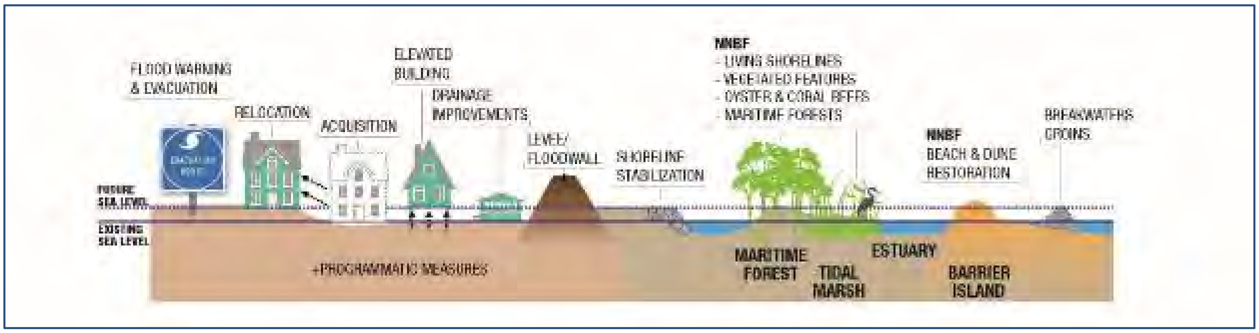
Credit: Adapted from US ACE

Figure 3-5. Risk reduction is a shared responsibility. Tools to reduce risk showing the responsible stakeholder(s). Residual risk is always present, even when all strategies are adopted.

Even with the best strategies in place, some risk will always remain. While actions that can reduce risks collectively help, there are always some unknown or unaddressed factors. This is called *residual risk*. Residual risk is the risk that remains after all risk management measures have been applied. Each community and individual has a choice regarding how much residual risk it is willing to accept, which in turn, informs the risk-reduction strategies it chooses to deploy.

[14] For information on projections for severe storms and other effects of climate change in New York, see NYSERDA's *2016* *ClimAid Report: Responding to Climate Change in New York* and the NYS Climate Change Science Clearinghouse .

[15] See separate *CRRA Model Local Laws guidance* for more information on municipal land use options to reduce risk.



Credit: Army Corps North Atlantic Coast-Comprehensive Study.

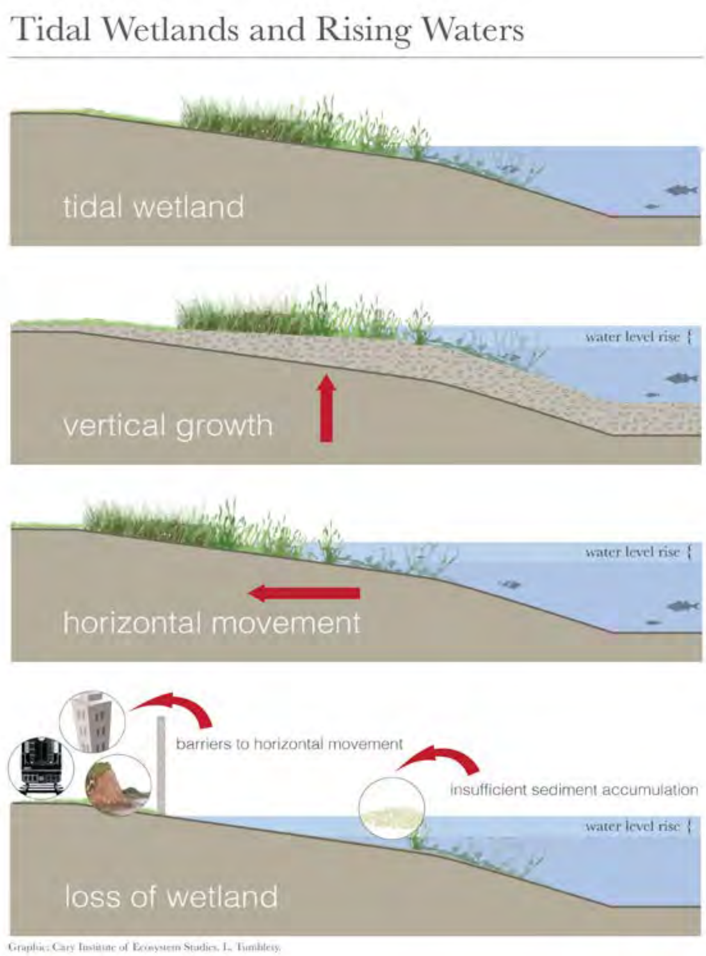
Figure 3-6. Examples of multiple lines of defense, using hard structural features and natural and nature-based features.

3.3.1 Threats to Natural Features

In addition to their inherent limits, once in place, natural resilience measures also face threats. Natural features and processes that reduce the risk of flooding and erosion may be compromised by any action that alters or restricts their sediment supply or their ability to respond to changes in the flow of water and sediment over time. Near-term threats include excavation, grading, filling, dredging, vegetation removal, invasive species, storm water runoff and adding structures and impervious surfaces, like pavement, in or near natural features. These actions can reduce their ability to absorb, diffuse, filter, redirect and convey water and water energy or directly cause erosion. Natural features can also be damaged or destroyed by extreme storms or repetitive storm events, but can recover if there is an adequate natural buffer area between the natural feature and development.

In the longer term, risk-reduction benefits of some natural features could be compromised by sea-level rise and development. For example, tidal fresh and saline wetlands (Figure 3-7) can continue to provide risk reduction if allowed to migrate inland or increase in elevation in response to sea-level rise. However, in many cases roads and structures are a barrier to inland migration. If these wetlands cannot migrate inland or be elevated, their erosion and flood reduction benefits will diminish over time. Other climate-related effects such as water-level variation, heat, drought and ocean acidification also may affect the ability of natural features to reduce risk.[16]

[16] See Appendix F for more information on the effects of climate change on natural features.



Credit: Cary Institute of Ecosystem Studies, L. Tumblety

Figure 3-7. Illustration of the how tidal wetlands are affected by sea-level rise.
Wetlands must have sufficient sediment to build up vertically and have sufficient space to "migrate" horizontally.

3.4 Examples of Natural Resilience Measures at Work

New York has many natural resilience measures already protecting assets from flooding and erosion. How natural features reduce risk is summarized in Table 3-2 below. Natural feature restoration restores these natural risk reduction benefits to an area. Nature-based features mimic these risk reduction benefits with constructed elements. Individual features vary in their ability to reduce risk based on their environmental context.

Table 3-2. How Natural Features Mitigate Flooding and Erosion Hazards

	Serves as a barrier	Provides roughness that reduces water velocity	Allows for storage and absorption of water by vegetation and infiltration into soil	Stabilizes sediment	Supplies sediment to other features that reduce risk	Provides a conveyance or draining function
Natural Features						
Bank	•	•		•	•	
Beach	•	•			•	
Bluff	•	•			•	
Inlets		•			•	•
Barrier Island	•	•		•	•	
Dune	•	•		•	•	
Floodplain		•	•			•
Forests		•	•	•	•	
Nearshore Area		•		•	•	
Maritime Forests		•	•	•		
Riparian Area		•	•	•		
Submerged Aquatic Vegetation		•		•		
Shellfish Beds/Reefs		•		•		
Shoals		•			•	
Stream		•			•	•
Wetlands, non-tidal freshwater		•	•	•		
Wetlands, tidal		•	•	•		

Specific examples are described and illustrated below.

Example 1: Natural tidal wetlands

Wetlands are a natural feature that can help reduce flooding from strong storms. In New York State, they occur in salt, brackish and freshwater. Their soils absorb water like a sponge and the dense vegetation of a healthy wetland creates friction that slows water movement (Figure 3-8).

Credit: NYS DEC.

Figure 3-8. A marine tidal wetland along the shoreline in Long Island.

Example 2: Natural Barrier Islands

Barrier islands reduce risk by serving as a barrier to waves and surge. They also reduce the velocity of waves and surge. Shoals and beaches on barrier islands supply sediment to other natural features that reduce risk (Figure 3-9).

Credit: ©The Nature Conservancy (Matt Levine).

**Figure 3-9. This barrier island in eastern Lake Ontario supports dunes and protects a wetland complex.
Denser vegetation forms on the top and landward side of the barrier and holds sand in place.**

Example 3: Nature-based shoreline stabilization

Rootwads (a tree trunk or root mass) and boulders, selectively embedded in or along banks, can reduce erosion and provide excellent cover and resting areas for insects and fish (Figure 3-10).

Credit: NYS DEC.

Figure 3-10. Lagoon of Strawberry Island in the Niagara River.
Tree trunk and rootwad installed and anchored in water to act as a low-profile sill that will attenuate waves and currents. Vegetation has become established behind the tree along the shoreline.

Example 4: Reconnected floodplains

Undeveloped floodplains allow concentrated flows coming from either the land or waterbody to slow down and spread out. This reduces sheer stress both on the shoreline and flood prone areas, reducing risk of erosion to stream and riverbanks. Floodplain vegetation creates friction that dissipates currents, wave action and storm surge.

Floodplain restoration can include removal of manmade flood protection structures such as berms, levees or dikes, removal of fill or reduction of impervious surfaces including structures and pavement (Figure 3-11). It can also include revegetation and restoration in wetland and riparian areas.

Credit: Delaware County Soil and Water Conservation District.

Figure 3-11. Soil and fill were excavated and removed to restore this floodplain in Walton, NY.
After vegetation becomes established the fence will be removed to reconnect the river with its floodplain. Photos show before and after excavation and regrading.

Example 5: Nature-based bluff stabilization

If bluff erosion threatens structures that cannot be relocated, the growth of healthy vegetation on the upland and along the crest and face of a bluff can help to stabilize the bluff and reduce erosion due to wind and water. Intercepting stormwater, to prevent it from flowing down the face of a bluff, can also prevent erosion (Figure 3-12).

Credit: S. Masullo, Goldberg and Rodler, Inc.

Figure 3-12. In response to erosion impacts from Hurricane Sandy, this bluff in Orient Point was stabilized using several layers of jute matting and native seaside plants, such as American Beach Grass and Bayberry, were planted on the crest and slope.
A small berm was added to the crest of the bluff to prevent stormwater running down the slope and minimize erosion. Temporary irrigation was used to ensure the plants became established. As the plants grow, they will provide coastal habitat and absorb greenhouse gases, while their root systems will hold the slope in place.

4. Natural and Nature-based Features That Reduce Risk of Flooding and Erosion

This section provides definitions of 17 natural features and 3 nature-based approaches that can reduce risk of flooding and erosion. Table 4-1 indicates whether each natural feature is typically found in the coastal, stream/riverine or upland environment. The table also indicates if a feature is highly dynamic or more stable. Highly dynamic features are those that are likely to shift dramatically as a result of sea level rise, storm surge, flooding and erosion. Relatively stable features are not static, they do move and change over time, but they typically don't experience dramatic change in response to strong storms. Additional detailed information on each feature can be found in individual feature descriptions.[17]

Table 4-1. Natural features that reduce risk and where they are commonly found

Natural Features that Reduce Risk	Coastal	Stream/Riverine	Upland
HIGHLY DYNAMIC (likely to move or change significantly as energy and water from storms or other sources is absorbed)			
Bank	✓	✓	
Barrier Island	✓	✓	
Beach	✓	✓	
Bluff	✓	✓	
Dune	✓	✓	
Floodplain	✓	✓	
Inlets	✓	✓	
Nearshore Area	✓		
Riparian Area		✓	
Shoals	✓		
Stream		✓	
Submerged Aquatic Vegetation	✓		
Wetlands, non-tidal freshwater[18]	✓		✓
Wetlands, tidal[19]	✓		
MORE STABLE			
Forests			✓
Maritime Forests	✓		
Shellfish Beds/Reefs	✓		

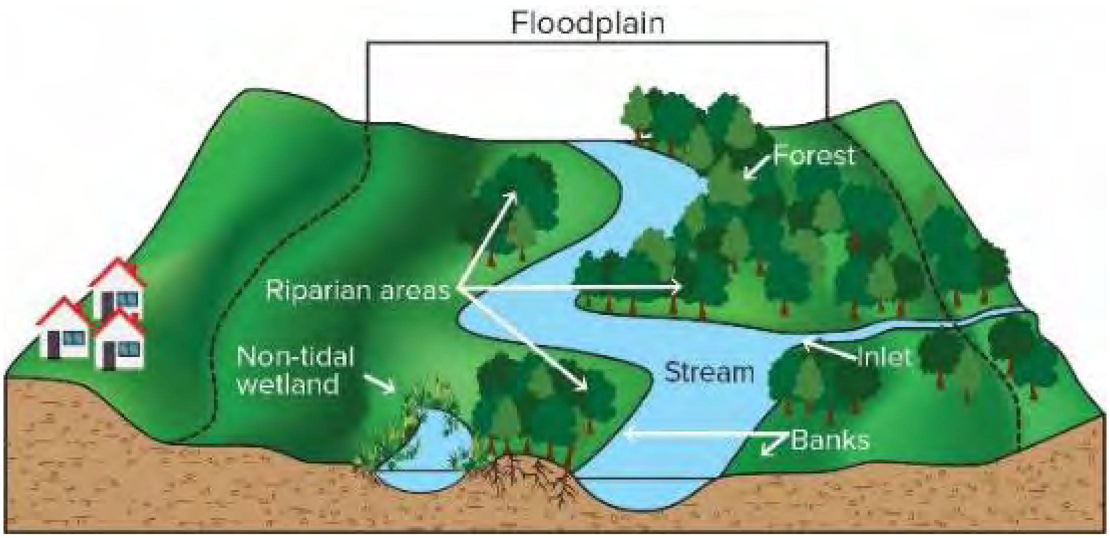
[17] Features listed here are described in more detail in individual feature descriptions found in Appendix A. Some definitions are unique to this guidance.

[18] Non-tidal wetlands are freshwater wetlands in upland areas and along the shores of the Great Lakes.

[19] Tidal wetlands include marine wetlands and brackish and freshwater wetlands of the Hudson River north of the Tappan Zee Bridge to the Federal Dam at Troy, all of which are subject to tides and sea-level rise.

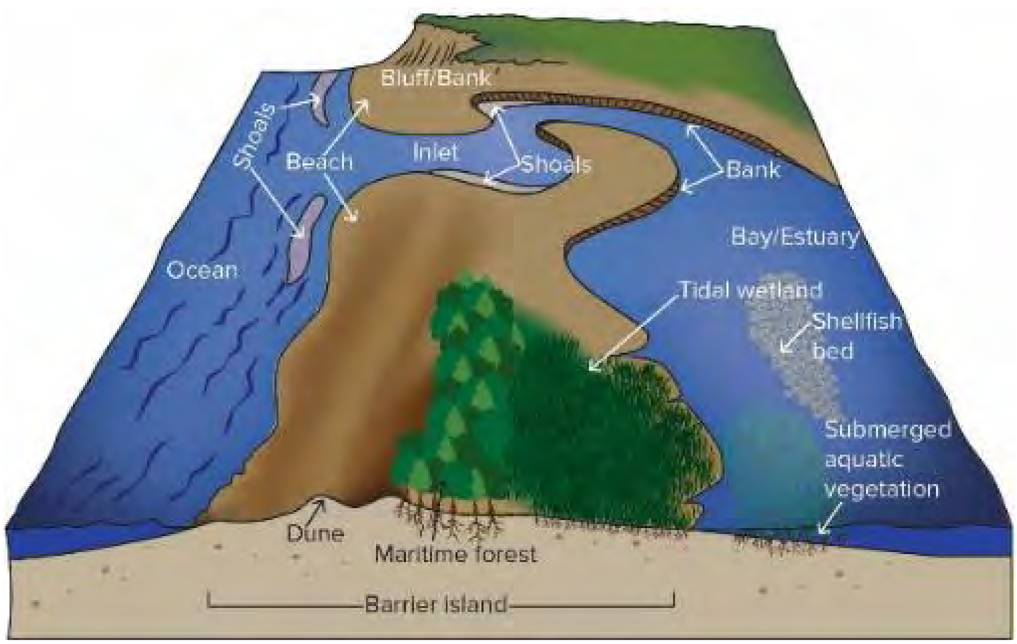
4.1 Natural Features

The following are definitions of natural features that reduce risk of flooding and erosion. Figure 4-1 and Figure 4-2 provide examples of where these natural features are found on the landscape. For more information on each feature, see Appendix A.



Credit: NYS DEC.

Figure 4-1. Diagram showing natural features that reduce risk in NYS upland areas.



Credit: NYS DEC.

Figure 4-2. Diagram showing natural features that reduce risk in NYS coastal areas.

Bank

Banks are part of the shore zone in stream, river, lake or coastal systems (Figure 1). Under stable conditions, banks confine water to a waterbody in a manner that balances the impacts of water energy with available sediment and bank geometry, without excess erosion. Banks respond to changes in sediment supply and water energy. Vegetated banks reduce risk by serving as a barrier, reducing water velocity, stabilizing sediment and supplying sediment to other features that reduce risk (Figure 2). See feature description for more information on how NYS regulates banks.

Barrier Islands

Barrier islands are sandy, ridge-like, features located parallel to, or in alignment with, the mainland and separated by a shallow sound, bay or lagoon. They are typically composed of several natural features, such as beaches, dunes and shoals, that can reduce risk. They may form as independent islands separated from the mainland, as elongated spits extending from headlands or across bay mouths. Barrier chains result when an otherwise continuous barrier is interrupted by one or more tidal inlets. As their name implies, barrier islands reduce risk by serving as a barrier to waves and surge. They also reduce the velocity of waves and surge. Shoals, beaches and dunes on barrier islands supply sediment to other natural features that reduce risk. Barrier islands can also have vegetated features like tidal wetlands and maritime forests that stabilize sediment. See feature description for more information on how DEC regulates shoreline areas on barrier islands.

Beach

Beaches extend from the top of the upland extent of wave action, often the base of a dune or bluff, to the lowest point of sediment movement in the adjacent waterbody. For the purposes of this guidance, the beach is only the land above mean low water. Underwater land below the low water line is typically considered the nearshore (see also shoal). Beaches reduce risk by reducing the velocity of waves and surge and supplying sediment to other natural features that reduce risk. See feature description for more information on how DEC regulates beaches.

Bluff

Bluffs are steep shoreline faces, or slopes, typically composed of sands, gravel and/or clays. Some bluffs may include exposed bedrock at or near the surface. Bluffs provide a source of sediment to beaches, wetlands and nearshore areas. This sediment is necessary to sustain these natural features and their wave attenuation and risk reduction benefits. See the feature description for more information on how DEC regulates bluffs.

Dune

A dune is an active accumulation of sand, formed primarily by wind action, with some elevation. Coastal dunes occur on a beach or further inland. Dunes reduce risk by serving as a barrier, reducing the velocity of waves and surge and supplying sediment to other natural features that reduce risk. Vegetated dunes also stabilize sediment.

Floodplain

A floodplain or flood-prone area is any land area susceptible to being inundated by water from any source. Floodplains extend upland from river, stream, lake, estuary and ocean shorelines, irrespective of whether they are natural or developed. Flooding frequency varies from location to location. During floods, floodplains convey water away from the main water body, allowing water to spread out and slow down, reducing risk.

Forest

A forest is an ecosystem characterized by at least 10 percent tree canopy cover, at least 1 acre in size and 120 feet in width, which is not primarily under agricultural or other specific non-forest land use. However, smaller areas of tree cover may provide similar benefits. Forests reduce risk by reducing water velocity and absorbing water. The vegetation also stabilizes soils.

Inlet

Inlets are natural channels or waterways that either periodically, or continuously, contain moving water and form a connecting link between two bodies of water. Adjacent waterbodies are the primary source of water passing through inlets. Breaches are a type of naturally occurring inlet. They typically form when storm waves or surge cut through coastal barrier islands or spits. A breach can also form if the water pressure in an enclosed waterbody is sufficient to break through a land barrier. Other examples of inlets include narrow waterways connecting bays, lagoons or lakes; tidal openings in barrier islands and river or tributary entrances to bays or lakes or oceans. Inlets reduce risk by reducing water velocity, supplying sediment to other natural features and conveying or draining water.

Maritime Forest

In the northeast, maritime forests occur in maritime portions of the coastal lowlands on sheltered backdunes, bluffs or more interior coastal areas not directly influenced by overwash, but affected by salt spray and wind-pruning. They are rare in New York. Known examples range from Caswell Cliff on Montauk Point, west to Friars Head on the north shore of Long Island and Sunken Forest on the south shore of Long Island. Successional maritime forests can also occur on areas of abandoned farmland or where vegetation has been burned or land cleared near marine communities. Species such as black and white oak, hickory, pitch pine, black cherry, serviceberry and black gum can be found in maritime forests. Species composition will vary based on site characteristics and land history. Maritime forests reduce risk by reducing water velocity, absorbing water and stabilizing sediment.

Nearshore

The nearshore area is an area of underwater lands that extend under and beyond waves breaking on the shoreline. This area is important for longshore sediment transport, a process that moves sand parallel to the shoreline and is the primary means of sediment supply to many natural features in coastal areas. The nearshore area also acts as a sediment reservoir, forming sandbars and shoals. The nearshore area reduces risk by reducing water velocity and supplying sediment to other natural features that reduce risk. Vegetated nearshore areas, like submerged aquatic vegetation and tidal wetlands can stabilize sediment. See feature description for more information on how NYS regulates nearshore areas.

Non-tidal (Freshwater) Wetland

Non-tidal wetlands are freshwater wetlands that are located inland and along the shorelines of the Great Lakes, Finger Lakes and large rivers. Wetlands are areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support a prevalence of vegetation typically adapted for life in saturated soil conditions. The presence of water-adapted vegetation is a primary indicator of a wetland. Non-tidal wetlands generally include swamps, marshes, bogs, embayments and similar areas, and are distributed widely, from floodplains in river valleys to headwater wetlands in high elevation mountains and ridges, to the wetlands that ring many areas of our Lake Ontario shoreline. Non-tidal wetlands reduce risk by reducing water velocity, absorbing water and stabilizing sediment. See feature description for more information on how NYS regulates non-tidal wetlands.

Riparian Area

Riparian areas are the lands bordering streams and rivers. They are transition zones between aquatic and upland areas that include the shoreline or bank and portions of the floodplain. Riparian areas have high levels of soil moisture, flood frequently and are inhabited by plants and animals that are adapted to wet conditions. Riparian areas reduce risk by reducing water velocity, absorbing water and stabilizing sediment.

Shellfish Beds and Reefs

A shellfish bed or reef is an intertidal or subtidal structure generated by the accumulation of living molluscan shellfish and dead associated shell from bivalves such as oysters, clams and mussels. Shellfish reefs and beds form three-dimensional structures in soft sediment, on rocky shores or in rubble in brackish conditions. They reduce risk by reducing water velocity and stabilizing sediment. See feature description for more information on how NYS regulates shellfish beds and reefs.

Shoals

A shoal or bar refers to “a natural, subaqueous ridge, bank or bar consisting of, or covered by, sand or other unconsolidated material, rising from the bed of a body of water (e.g., estuarine floor) to near the surface. It may be exposed at low water.” Shoals and bars consist of sediments carried by flowing water along shorelines or through inlets, and deposited in locations where the current speeds slow to the point that sediment can no longer be carried. They can accumulate in inlets, lakes, streams, rivers and tidal areas. Shoals and bars reduce risk by reducing water velocity and supplying sediment to other natural features. See feature description for more information on how NYS regulates in-water areas.

Stream

A stream or river is a natural waterway with a detectable current, having defined bed and banks, with perennial, intermittent or ephemeral flow. Streams and rivers drain water from the land within a watershed. The bed is the bottom of a stream or river. The bank is the side of the stream or river, making up the land area immediately adjacent to, and which slopes toward, the bed, and which is necessary to maintain its structure and integrity. Natural meanders are curves in the stream that slow down the water and reduce the energy that could cause erosion. Physical diversity, vegetation and the meanders of a stream reduce risk by slowing water velocity and stabilizing sediment. Streams also supply sediment to other natural features that reduce risk, like wetlands, and convey water, draining flooded areas. See feature description for more information on how NYS regulates the bed and banks of streams.

Submerged Aquatic Vegetation

Submerged aquatic vegetation (SAV) are rooted, vascular, flowering plants that, except for some flowering structures, live and grow below the water surface where light can reach them. SAV beds reduce risk by reducing water velocity and stabilizing sediment.

Tidal Wetland

Tidal wetlands (or marshes) are areas that are regularly inundated or saturated by saline water or, in estuaries, freshwater, at a frequency and duration sufficient to support vegetation typically adapted for life in saturated soil conditions. These areas can be either inundated twice daily by tides or only periodically flooded during high or "spring" tides a few times a month. Along New York's marine coastline the most typical tidal wetland types are salt marshes and mudflats or tidal flats. Along the Hudson River estuary, tidal wetlands range from brackish to freshwater conditions. Tidal wetlands reduce risk by reducing water velocity, absorbing water and stabilizing sediment. See feature description for more information on how NYS regulates tidal wetlands.

4.2 Nature-based Techniques

4.2.1 Constructed Stormwater Green Infrastructure Techniques

Constructed stormwater green infrastructure (CSGI) techniques mimic, accommodate or enhance the natural capture and infiltration of rainwater into the ground to reduce the risk of flooding and erosion to human assets in upland areas. Infiltration allows water to soak into the ground rather than running off into low-lying areas or flowing directly into streams. CSGI rely on vegetation alone or combined with grading, fill or addition or removal of structural components.

4.2.2 Nature-based Coastal Techniques

Nature-based coastal techniques mimic, accommodate or enhance natural shoreline processes to reduce the risk of erosion to human assets on coastal (ocean, estuarine, bay, large river and lake) shorelines. Depending on the site location, scale and design, they may also reduce the risk of flooding. Nature-based coastal techniques rely on vegetation alone or combined with grading, fill or addition or removal of structural components. They are generally appropriate for shorelines that are exposed to low to moderate energy waves and currents. They may also be exposed to tides and saline environments. These techniques fall into three general categories: bank stabilization, in-water features and floodplain reconnection.

4.2.3 Nature-based Stream Techniques

Nature-based stream techniques mimic, accommodate or enhance natural shoreline processes to reduce the risk of erosion to human assets on stream and riverine shorelines. Depending on the site location, scale and design, they may also reduce the risk of flooding. Nature-based stream techniques rely on vegetation alone or combined with grading, fill or addition or removal of structural components. These techniques are generally appropriate for shorelines that are exposed to low to moderate energy currents with little to no fetch or wind-driven waves. They are designed to mimic or integrate with natural stream shape (morphology), water movement (hydrology) and sediment transport processes. They include a wide variety of approaches that fall into three general categories: stream stabilization techniques (bank and bed), floodplain reconnection and stream daylighting.

5. Glossary

- **Accretion** – the gradual and imperceptible accumulation of land in a water body as a result of natural processes such as a deposit of sediment upon the shore, or by a recession of the water from the shore.
- **Adaptation** – planning, communication and preparedness for projected changes in climate and extreme weather events
- **Adaptive management** – the incorporation of new information about management impacts back into the decision-making process so that resource management can be adjusted on the basis of what has been learned.
- **Aeolian processes** – erosion, transportation and deposition of sediment by the wind
- **Attenuation (of waves)** – the weakening of the strength or intensity of waves, reducing wave height.
- **Berm** – an artificial raised ridge or bank parallel to the shoreline.
- **Beach nourishment** – large volumes of sand added from an outside source to an eroding beach to widen the beach and move the shoreline seaward.
- **Bio logs** – long cylindrical structures composed of coconut husks or straw or other natural fiber confined with natural fiber netting. Bio logs are laid parallel to the shore, and are intended to help attenuate wave energy or prevent minor slides while encouraging sediment deposition and plant growth.
- **Breakwater** – an offshore structure intended to reduce the force of wave action. It may also encourage sediment accretion on the shore side of the structure. It can be floating or fixed to the ocean/lake floor, attached to shore or not, and continuous or segmented.
- **Buffer** – a vegetated area between a waterbody and land use
- **Bulkhead** – a shoreline protection technique comprising of a vertical wall that prevents the loss of soil and erosion of the shore. It can be made of a variety of materials including rock, steel, concrete and wood.
- **Carbon sequestration** – the removal and storage of carbon from the atmosphere in carbon sinks (such as oceans, forests or soils) through physical or biological processes, such as photosynthesis.
- **Coastal Erosion Hazard Areas (CEHA)** – areas mapped by NYS DEC pursuant to Article 34 of the Environmental Conservation Law.
- **Co-benefit** – indirect benefits, such as water and air quality improvements, carbon sequestration and recreational benefits associated with natural and nature-based features

- **Constructed stormwater green infrastructure** – Techniques that manage stormwater runoff, or water from rain or snow that "runs off" across the land, primarily by promoting or mimicking natural rainwater infiltration into soils and groundwater.
- **Cross-shore sediment transport** – the cumulative movement of beach and nearshore sand perpendicular to the shore by the combined action of tides, wind and waves, and currents. These forces usually result in an almost continuous movement of sand either suspended in the water column or at the seafloor.
- **Dredging** – in-water excavation gathering up bottom sediments and disposing of them at a different location.
- **Downdrift** – in the direction of net longshore sediment transport or in the direction of net sediment movement parallel to the shoreline.
- **Ebb-tide** – the period between high tide and low tide, during which water flows away from the shore
- **Ecosystem** – a dynamic complex of plant, animal and microorganism communities and their physical environment, all of which interact as a functional unit.
- **Ecosystem services** – benefits that ecosystems provide, directly or indirectly, to the environment and human populations.
- **Erosion** – the action of wind, water and ice that remove soil, rock or dissolved material from one location on the earth's crust, such as a shoreline, and transport it to another location, such as into the water column and away from the source.
- **Evapotranspiration** – the sum of the water lost to the atmosphere from evaporation from the land and water-body surfaces and transpiration from plants
- **Feature** – A structure designed to reduce risk of erosion and/or flooding.
- **Fetch** – the distance over water that the wind blows, unobstructed, in a single direction. Fetch is an important component of wave generation.
- **Geotextiles** – permeable fabrics which, when used in association with soil, have the ability to separate, filter, reinforce or drain.
- **Green infrastructure** – the integration of natural and nature-based features and processes into investments in community, environmental and economic resilience. See also constructed stormwater green infrastructure.
- **Groin** – a shore-perpendicular structure intended to build up an eroded beach or to slow the erosion of a stretch of beach by trapping sediment moving downdrift along the shoreline.
- **Hard structural features** – engineered structures, like bulkheads and seawalls, that are typically constructed of stone, pressure-treated wood, compacted earth, or hard human-made materials (concrete, metal, etc.) and designed to hold back or control water and/or sediment to reduce the effects of flooding or erosion. These features

typically disrupt natural features and processes and have limited or no living components.

- **Hazard** – The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.
- **Hybrid** – See "nature-based features." Flood and erosion risk reduction measures that combine hard structural features with natural materials and components that mimic natural features and processes.
- **Impervious cover or surface** – hard surfaces associated with development (e.g. paved surfaces, rooftops, concrete sidewalks, etc.) that prevent water run-off from naturally percolating into the soil.
- **Invasive vegetation (or species)** – introduced plant (or animal) species that are able to establish on many sites, grow quickly and spread to the point of disrupting ecosystems in a harmful way, causing damage to the environment, economy or human health.
- **Jetty/Jetties** – Hard shore-perpendicular structures, typically made of concrete or stone, built to protect a harbor or inlet from waves and wakes and/or maintain a navigable waterway.
- **Landward** – the side of the shoreline facing the land
- **Levee** – An earthen embankment, floodwall or structure along a watercourse whose purpose is flood risk reduction and/or water conveyance.
- **Littoral** – close to shore of a river, ocean or lake
- **Littoral drift** – the transport of sediment along and parallel to the shoreline as a result of the combined action of waves and currents
- **Live crib walls** – vertical retaining wall used to control erosion made of interlocking concrete or wood elements and filled with alternating layers of soil and live branches. Live branches eventually establish themselves and their roots anchor the bank and eventually take over the function of the crib structure.
- **Living shoreline** – Shoreline erosion control techniques that incorporate natural living features alone or in combination with structural components.
- **Longshore sediment transport** – the cumulative movement of beach and nearshore sediment parallel to the shore by the combined action of tides, wind and waves and currents.
- **Marine District** – the marine and coastal district waters of New York state; it refers to all ocean waters that are within three nautical miles from the state's coastline, including the Atlantic Ocean, Long Island Sound and embayments, as well as the tidal Hudson River waters running south of the Tappan Zee Bridge. Marine and coastal district waters

are governed by both state and town municipal regulation and authority. See http://www.dec.ny.gov/permits/95483.html for more information.

- **Meander** – A sinuous bend in a watercourse or river.
- **Measure** – An action taken to reduce risk from erosion and/or flooding.
- **Mitigation** – Actions to eliminate or reduce the frequency, magnitude or severity of exposure to risks, including actions in one location to counter increasing risk at another.
- **Native vegetation (or species)** – a plant (or animal) that is part of the balance of nature that has developed over hundreds or thousands of years in a particular region or ecosystem. It is typically contrasted with invasive vegetation (or species), which are artificially introduced and able to establish on many sites, grow quickly and spread to the point of disrupting ecosystems in a harmful way, causing damage to the environment, economy or human health.
- **Natural features** – landforms (features) created by physical, geological, biological and chemical processes that evolve over time through the forces of nature. [20] These include features like wetlands, floodplains, dunes and barrier islands. Individual features are part of larger natural systems and are linked by natural processes.
- **Natural resilience measure** – the conservation or restoration of a natural feature or construction of a nature-based feature.
- **Nature-based features** – features that mimic natural features and processes and are engineered to provide specific services, such as erosion or stormwater management, flood risk reduction or water quality improvement. They typically incorporate living materials with structural materials and minimize disturbance of existing habitat. For shorelines and stream banks, nature-based features are sometimes referred to as "hybrid," "living shorelines," "bio-engineered," or "bio-technical." Nature-based features for stormwater management may be called "constructed stormwater green infrastructure" or "low impact development" methods.
- **Nearshore** – Lands underwater near the shore. The DEC regulatory definition is the area beginning at mean low water and extending, perpendicular to the shoreline, to a point where mean low water depth is 15 feet or to a horizontal distance of 1000 feet from the mean low water line, whichever is greater.
- **Non-structural measures** – generally those activities that do not involve the direct management of water flows, but instead manage flooding and erosion by moving community assets out of areas at risk or preventing siting of new structures in these areas.
- **Offshore** – Seaward of the nearshore region.
- **Resilience** – the ability to anticipate, prepare for and adapt to changing conditions and withstand, respond to and recover rapidly from disruptions. Also defined as the capacity

[20] Definitions of natural feature and nature-based features are adapted from USACE (2015) and FEMA (2015).

of social, economic and environmental systems to cope with a hazardous event, trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation.

- **Restoration** – actions to remove barriers and to re-establish natural features and processes that have been degraded or altered to enhance the natural risk-reduction capacity of the feature and improve ecological systems.
- **Revetment** – a sloping structure, consisting of a facing of stone or concrete units, designed to control shoreline erosion.
- **Riparian** – associated with shorelands of non-tidal waters, such as streams.
- **Rip-rap** – a shoreline protection technique used to armor a sloping shore using a permanent, erosion resistant ground cover of large, loose rock or cobble to protect the finer sized sediments from eroding. Rip-rap can also refer to the stone material itself.
- **Risk** – The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability or likelihood of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur (Risk = Probability of occurrence x Impact (or consequence). It is used to refer to the potential, when the outcome is uncertain, for adverse consequences on lives, livelihoods, health, ecosystems and species, economic, social and cultural assets, services (including environmental services) and infrastructure.
- **Risk-reduction capacity** – the ability of a natural, nature-based or hard structural feature to lessen the exposure to danger, specifically from flooding and erosion.
- **Sea level rise** – The worldwide increase in the volume of the world's oceans that occurs as a result of thermal expansion and melting ice caps and glaciers. See *Projected sea-level rise* for NYS for CRRA purposes.
- **Seawall** – A shore parallel structure constructed on high energy shorelines and designed to dissipate the energy of larger waves and/or hold back floodwaters.
- **Seaward** – the side of the shoreline facing the sea
- **Sediment transport** – is the movement of solid particles (sediment), typically due to a combination of gravity acting on the sediment and/or the movement of the water carrying the sediment.
- **Shoreline** – A line of contact between the land and water.
- **Shore zone** – The zone of contact of the surface of a water body and the land, typically reaching above extreme high and below extreme low water respectively, where strong and direct interactions tightly link the terrestrial and aquatic ecosystems.
- **Shoreline stabilization** – a range of shoreline management responses designed to slow the rate of erosion and dissipate energy from waves or currents through natural (e.g., vegetation), nature-based or hard structural measures.

- **Spring high tide** – Tides of increased range or tidal currents of increased speed occurring semimonthly as the result of the Moon being new or full.
- **Storm surge** – The temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions (low atmospheric pressure and/or strong winds). The storm surge is defined as being the excess above the level expected from the tidal variation alone at that time and place.
- **Streamway** – the area adjacent to the watercourse that provides space for the stream channel to migrate over time and allows for natural dynamic changes in width, depth, slope and channel meander pattern of the stream.
- **Soft structural features** – structures that mimic characteristics of natural features, but are engineered by humans to provide specific services, such as erosion or stormwater management, flood risk reduction and water quality improvement.
- **Structural measures** – actions to construct hard structural features using materials not native to the site (e.g. steel, concrete) to control or direct water and/or sediment movement.
- **Updrift** - in the opposite direction of net longshore sediment transport or in the opposite direction of net sediment movement parallel to the shoreline.
- **Vulnerability** – The propensity to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.
- **Washover** – A fan-shaped body of sediment that is transported landward by marine waters flowing through or across a coastal barrier such as a barrier bar or island. Such bodies are often formed during storms when the barriers are overtopped.
- **Watercourse** – A channel or conveyance of surface water having defined bed and banks, whether natural or artificial, with perennial or intermittent flow.
- **Watershed** – a basin-like region or area bounded peripherally by high points and ridgelines and draining ultimately to a particular watercourse or body of water
- **Wave energy** – describes the force a wave is likely to have on a shoreline or shore zone. Wave energy at a specific site depends on environmental factors like shore orientation, wind, channel width and bathymetry. Boat wakes can also generate waves.
- **Wetland migration** – the movement of tidally-influenced wetland vegetation in response to sea-level rise or other changes in water level.

6. References

1. ARCADIS. (2014). Coastal Green Infrastructure Research Plan for New York City. Retrieved from http://www.dec.ny.gov/lands/100057.html

2. Bridges, T. S., Wagner, P. W., Burks-Copes, K. A., Bates, M. E., Collier, Z. A., Fischenich, C. J., ... & Russo, E. J. (2015). Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience (No. ERDC-SR-15-1). Vicksburg, MS: Engineer Research and Development Center, Environmental Lab.

3. Coastal Green Infrastructure and Ecosystem Services (CGIES) Task Force. (2015). Ecosystem Service Assessment: Research Needs for Coastal Green Infrastructure. Washington, D.C.: Office of Science and Technology Policy. Retrieved from https://www.whitehouse.gov/sites/default/files/microsites/ostp/cgies_research_agenda_final_082515.pdf

4. Duarte, C. M., Losada, I. J., Hendriks, I. E., Mazarrasa, I., and Marba, N. (2013). The Role of Coastal Plant Communities for Climate Change Mitigation and Adaptation. *Nature Climate Change*, 3: 961–968.

5. Federal Emergency Management Agency (FEMA). (2013). Mitigation Ideas: A Resource for Reducing Risk to Natural Hazards. Washington, D.C. Retrieved from http://www.fema.gov/media-library-data/20130726-1904-25045-0186/fema_mitigation_ideas_final508.pdf

6. Federal Emergency Management Agency (FEMA). (2015). Guidelines for Implementing Executive Order 11988, Floodplain Management, and Executive Order 13690, Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input (October 8, 2015). Retrieved from https://www.fema.gov/media-library-data/1444319451483-f7096df2da6db2adfb37a1595a9a5d36/FINAL-Implementing-Guidelines-for-EO11988-13690_08Oct15_508.pdf

7. Horton, R., Bader, D., Rosenzweig, C., DeGaetano, A., & Solecki, W. (2014). Climate Change in New York State: Updating the 2011 ClimAID Climate Risk Information. New York State Energy Research and Development Authority (NYSERDA), Albany, New York.

8. Livermont, E. A., Hauser, E., Tobitsch, C., Auermuller, L., Valencik, K., & Hice-Dunton, L. (2014). Proceedings for Regional (NY-NY-DE) Dialogue to Advance Sustainable Shorelines along Sheltered Coasts (October 4, 2013). Staatsburg, NY: Hudson River Sustainable Shorelines Project. Retrieved from http://hrnerr.org

9. National Academy of Engineering (NAE) and National Research Council (NRC). (2009). The New Orleans Hurricane Protection System: Assessing Pre-Katrina Vulnerability and Improving Mitigation and Preparedness. Washington, D.C.: The National Academies Press. Retrieved from https://doi.org/10.17226/12647

10. National Research Council (NRC). (2014). Reducing Coastal Risk on the East and Gulf Coasts (p. 96). Washington, D.C.: The National Academies Press. Retrieved from https://doi.org/10.17226/18811

11. New York State (NYS) 2100 Commission. (2013). Recommendations to Improve the Strength and Resilience of the Empire State's Infrastructure, p.12. Retrieved from http://nyssmartgrid.com/wp-content/uploads/2013/02/NYS2100.pdf

12. New York State Department of Environmental Conservation (NYS DEC). (2015). Observed and Projected Climate Change in New York State: An Overview Developed for the Community Risk and Resiliency Act (CRRA) Drafting Teams Final – 12/31/15. Retrieved from http://www.dec.ny.gov/docs/administration_pdf/climbkgncrra.pdf

13. New York State Department of Environmental Conservation (NYS DEC). (2017). Tidal Wetlands Guidance Document: Living Shoreline Techniques in the Marine District of New York State. Retrieved from https://www.dec.ny.gov/docs/fish_marine_pdf/dmrlivingshoreguide.pdf

14. New York State Department of Environmental Conservation (NYS DEC). (2018). How to Get Certified. Retrieved from http://www.dec.ny.gov/energy/96511.html

15. New York State Department of Environmental Conservation (NYS DEC). (n.d.). Protection of Waters Program. Retrieved from http://www.dec.ny.gov/permits/6042.html

16. New York State Department of Homeland Security and Emergency Services (NYS DHSES). (2014). 2014 New York State Hazard Mitigation Plan.

17. New York State Department of State (NYS DOS). (2017). New York State Coastal Management Program and Final Environmental Impact Statement. Retrieved from https://www.dos.ny.gov/opd/programs/pdfs/NY_CMP.pdf

18. New York State (NYS). (2013). Guidance for New York Rising Community Reconstruction Plans. Retrieved from https://stormrecovery.ny.gov/sites/default/files/documents/Guidance_for_Community_Reconstruction_Plans.pdf

19. NOAA Office for Coastal Management (OCM) and U.S. Census Bureau. (2013). Decadal Demographic Trends for Coastal Zone Boundaries. Retrieved from https://coast.noaa.gov/dataregistry/search/dataset/info/demographictrends

20. NOAA Office for Coastal Management (OCM). (n.d.). NOAA Digital Coast. Retrieved from https://coast.noaa.gov/digitalcoast/

21. Regional Plan Association. (2018). The New Shoreline: Integrating Community and Ecological Resilience around Tidal Wetlands. A Report of the Fourth Regional Plan. Retrieved from www.rpa.org

22. Restore America's Estuaries. (2015). Living Shorelines: From Barriers to Opportunities. Arlington, VA. Retrieved from https://www.estuaries.org/images/stories/RAEReports/RAE_LS_Barriers_report_final.pdf

23. Rosenzweig, C., Solecki, W., DeGaetano, A., O'Grady, M., Hassol, S., & Grabhorn, P., Eds. (2011). Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation (Section 9.2.4, p. 309). Albany, NY: New York State Energy Research and Development Authority (NYSERDA).

24. Seitz, R., Breitburg, D., Targett, T., & Prosser, D. (2016). Upland Development and Shoreline Hardening Negatively Impact Estuarine Benthos, Fish, and Waterbirds. NOAA Seminar Presentation.

25. Strayer, D., & Tumblety, L. (2015). Managing Shore Zones for Ecological Benefits: Handbook. Staatsburg, NY: Hudson River Sustainable Shorelines Project, Hudson River National Estuarine Research Reserve. 64 pp. Retrieved from https://www.hrnerr.org/doc/?doc=273743856

26. Sweet, M., Kopp, R., Weaver, C., Obeysekera, J., Horton, R., Thieler, R., & Zervas, C. (2017). Global and Regional Sea Level Rise Scenarios for the United States. NOAA Technical Report NOS CO-OPS 083. Retrieved from https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_sea-level_rise_Scenarios_for_the_US_final.pdf

27. Title 6 of the New York Codes, Rules and Regulations (6 NYCRR), Part 490.4: Projections. Retrieved from https://www.dec.ny.gov/regulations/103877.html

28. Title 6 of the New York Codes, Rules and Regulations, Part 505: Coastal Erosion Management.

29. Title 6 of the New York Codes, Rules and Regulations (6 NYCRR), Part 505.6: Standards for Issuance of Coastal Erosion Management Permits.

30. Title 6 of the New York Codes, Rules and Regulations (6 NYCRR), Part 505.9: Erosion Protection Structures.

31. Title 6 of the New York Codes, Rules and Regulations (6 NYCRR), Part 661: Tidal Wetlands—Land Use Regulations. Retrieved from http://www.dec.ny.gov/permits/6039.html

32. Title 6 of the New York Codes, Rules and Regulations (6 NYCRR), Part 663: Freshwater Wetlands Permit Requirements.

33. Title 6 of the New York Codes, Rules and Regulations (6 NYCRR), Part 664: Freshwater Wetlands Maps and Classification.

34. Title 6 of the New York Codes, Rules and Regulations (6 NYCRR), Part 665: Local Government Implementation of the Freshwater Wetlands Act and Statewide Minimum Land-Use Regulations for Freshwater Wetlands.

35. U.S. Army Corps of Engineers (USACE). (2002). Coastal Engineering Manual (6 volumes). Engineer Manual 1110-2-1100. Washington, D.C. Retrieved from *http://chl.erdc.usace.army.mil/cem*

36. U.S. Army Corps of Engineers (USACE). (2015). Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience: Final Report (ERDC SR-15-1). Engineer and Research Development Center. Retrieved from *http://www.nad.usace.army.mil/Portals/40/docs/NACCS/NNBF%20FINAL.pdf*

37. U.S. Army Corps of Engineers (USACE). (2016). National Nonstructural Flood Proofing Committee Website. *http://www.usace.army.mil/Missions/Civil-Works/Project-Planning/nfpc*

38. U.S. Environmental Protection Agency (EPA). (n.d.-a). Green Infrastructure: Coastal Resiliency. Retrieved from *https://www.epa.gov/green-infrastructure/coastal-resiliency*

Appendices

Appendix A: Feature Descriptions

A.1 – Banks

What is a bank?

Banks are part of the shore zone in stream, river, lake or coastal systems (Figure A.1-1). Under stable conditions, banks confine water to a waterbody in a manner that balances the impacts of water energy with available sediment and bank geometry, without excess erosion. Banks respond to changes in sediment supply and water energy. Vegetated banks reduce risk by serving as a barrier, reducing water velocity, stabilizing sediment and supplying sediment to other features that reduce risk (Figure A.1-2).

Banks can move or change suddenly and significantly as energy and water from strong storms or other sources are absorbed. *For this reason, structures or assets sited on or near banks are considered to be at greater risk.*

The NYS regulatory definition of a bank is that land area immediately adjacent to and which slopes toward the bed of a watercourse, and which is necessary to maintain the integrity of a watercourse[21]. Although all waterbodies have banks, in NYS this regulatory definition is typically applied to protected stream and riverine systems and some coastal areas. [22]

Credit: H. Malcolm.

Figure A.1-1. Bank in the shore zone along the Hudson River.

[21] Use and Protection of Waters 6NYCRR Part 608, 1994, *http://www.dec.ny.gov/permits/6554.html*

[22] To determine if a permit is required for a project at a specific location contact the Division of Environmental Permits in the appropriate DEC Regional Office.

Credit: L. Potter.

Figure A.1-2. The gradient of a typical natural lake bank or shoreline and its vegetation, from the upland to underwater (A-D).

How do banks reduce risk?

Banks are part of a larger natural system which, in coastal areas, includes beaches, bluffs, floodplains nearshore areas, tidal wetlands and non-tidal wetlands (in the Great Lakes). In upland areas, the larger system includes streams, riparian areas, floodplains, non-tidal wetlands and forests. Conserving this larger natural system reduces risk near banks. Risk reduction will vary based on management of these individual features. Other measures may be needed to further reduce risk from large surge or flood events.

Banks reduce risk by providing the following risk reduction benefits:

- **Serve as a barrier:** Banks hold water within a water body.
- **Reduce water velocity:** Vegetated banks are rough and create friction that reduces water velocity reducing vulnerability of the bank to erosion from overland flow and from flooding, waves, or surges. Sloped beaches, shoals and nearshore areas reduce incoming waves by friction and dissipate wave and current forces.
- **Supply sediment:** Eroding banks supply sediment to the system, which is necessary to support the building of beaches and dunes, non-tidal and tidal wetlands, nearshore areas, shoals and other natural features that reduce the risk of erosion downstream or in adjacent shoreline areas.
- **Stabilize soil:** Root systems from trees and shrubs hold the soil in place on the bank.

Forces and conditions that banks can mitigate to reduce risks to people and communities

- Currents generally parallel to the shoreline causing damage from erosion, floating debris or the mobilization of ice

- Waves, wakes and surges generally perpendicular to the shoreline causing damage from erosion, floating debris, or the mobilization of ice

Human activities that reduce or impair risk-reduction capacity

- Armoring, hardening or straightening the bank or shoreline, and/or using either shore-perpendicular hard structures (e.g., groins) or in-water parallel hard structures (e.g., breakwaters) can interrupt and reduce sediment supply to adjacent banks and other natural features and lead to erosion and loss of bank vegetation.
- Shoreline armoring can reflect and refract incoming waves or currents, accelerating erosion at the base of the structure and on adjacent banks. For example, because of wave reflection off its face, a vertical bulkhead can become eroded at its base (scour) or refracted waves can erode adjacent shoreline or shore zone areas (flanking).
- Land use changes in the watershed, floodplain and riparian area (such as an increase in impervious surfaces) that increase stormwater runoff can increase the magnitude and energy of flood flows in the stream and lead to erosion of the bank (Hollis, 1975; Leopold, 1994; Ehrhart, 2003; Chemung County SWCD, 2006; NYS DEC, 2015).
- Excavation or removal of bedrock, gravel and sand within or near a bank can reduce bank stability.
- The banks of larger, navigable waterways can be impacted by erosion caused by the wakes of motorized vessels.
- Removal of woody debris within a stream or river bed may result in acceleration of stream velocities, flow and erosion of the bed and bank. Woody debris should only be removed when necessary (i.e. if assets are at risk from damming or localized scour). (Chemung County SWCD, 2006)
- Alterations of bank elevation in streams can affect bank stability, erosion, deposition and channel formation. If the bank is raised too high and the channel is disconnected from the floodplain, then water energy and bank erosion is accelerated during high flow events. If the bank is too low and water flows outside the channel into the floodplain too easily, sediment deposition may increase and new channels may form outside the existing channel. (Chemung County SWCD, 2006)
- Adjacent land uses (e.g. agriculture, construction activities) and bank modification (e.g. excavation or penetration by utilities or infrastructure) may result in excess sediment being introduced into the waterbody, with associated effects on bank stability and potential bank or channel migration.
- Deep rooted woody vegetation is critical to maintaining bank stability. Disturbances in vegetation coupled with invasive species introductions can alter the root system and replace trees and vegetation that reduce soil erosion with plants and shrubs that have weaker root structures, such as Japanese knotweed.

- In coastal areas, improper siting of offshore dredging sand sources may reduce sediment supply to adjacent areas and diminish the sand/sediment supplied to the bank or beach leaving the shoreline more susceptible to erosion.

Other benefits

- **Economic:** Banks provide access to waterways for industry, commerce, navigation, fishing, recreation and tourism. Banks are a source of sand and gravel deposits for commerce and industry.
- **Habitat:** Banks create a transitional area from terrestrial to aquatic ecosystems as well as a corridor for wildlife. Roughness elements of banks (vegetation, bank irregularities, sediment particles of different sizes and bedforms) create aquatic habitat (FISRWG, 1998).
- **Extreme heat mitigation:** Vegetated natural areas can mitigate extreme heat and the urban heat island effect by providing shade and/or through the cooling effect of evapotranspiration, which releases water vapor and heat energy to the atmosphere. Tree canopies along on banks shade the waterbody, moderating the water temperature.
- **Community, culture and recreation:** Communities value vegetated banks for scenery and providing access for fishing, swimming, hiking, boating, hunting, trapping and bird and wildlife watching. Shoreline areas are also closely coupled with some communities' sense of place and local cultural traditions.
- **Water filtration/quality:** Densely vegetated banks filter runoff and provide water quality benefits.
- **Carbon sequestration:** Vegetated banks sequester carbon.

Possible effects of changes in climate and water levels on banks

Sea-level rise/water level change

- Over many decades rising sea levels will cause the location of bluffs and banks to move landward in tidal areas.

Stronger storms

- More extreme storms can result in strong waves and currents, causing scouring and loss of vegetation that reduces bank stability, integrity and function.
- Risk from flooding (elevation and extent) on streams and rivers will only be mitigated until the stream reaches the top of its banks, after which it will overtop the banks and move onto the floodplain.

- Extreme storm events can cause significant erosion and change the supply of sediment along banks.

Short-term drought

- Drought may cause vegetation to die, reducing root and vegetation stabilization of the bank.

Restored or nature-based banks

Restored Natural Bank: For examples of restored banks, see inlets, stream, beach, bluff and riparian area feature descriptions.

Nature-based Bank: Depending on their location, nature-based banks could incorporate nature-based coastal and stream techniques or constructed stormwater green infrastructure.

Examples of locations where restored or nature-based banks have been implemented

- DEC's "Trees for Tribs" Program: This program is actively replanting riparian areas to restore banks in targeted areas *www.dec.ny.gov/animals/77710.html*
- Saw Mill River, Yonkers, NY: This river was uncovered from pipes and a nature-based bank and stream were created to attract people to the waterfront and improve habitat and water quality *http://www.yonkersny.gov/work/department-of-planning-development/projects/daylighting-of-the-saw-mill-river*
- New York City drinking water watershed: The Catskill Stream Buffer Initiative provides information and assistance to landowners in stewardship of their banks and riparian areas through protection, enhancement, management or restoration *http://catskillstreams.org/catskill-streams-buffer-initiative/*
- Hudson River Estuary: A variety of nature-based methods have been employed on the banks of the Hudson River Estuary *https://www.hrnerr.org/hudson-river-sustainable-shorelines/demonstration-site-network/*

Refer to feature descriptions for inlets, stream, beach, bluff and riparian area and nature-based coastal and stream techniques or constructed stormwater infrastructure for more information on examples of where banks have been implemented or restored.

Factors to consider in design, construction and maintenance for restoration (if a natural feature) or construction (if a nature-based feature)

- Refer to feature descriptions for specific bank types along inlets, streams, *beaches*, bluffs and riparian areas and nature-based coastal and stream techniques and constructed stormwater green infrastructure for more information on design considerations.

- Consult with the appropriate regulatory agencies before beginning a project near a bank.

Sources

1. Chemung County Soil & Water Conservation District (SWCD). (2006). Stream Processes: A Guide to Living in Harmony with Streams. Retrieved from *http://www.catskillstreams.org/pdfs/chemungstreamguide.pdf*

2. Davidson-Arnott, R. (2010). An Introduction to Coastal Processes and Geomorphology. New York: Cambridge University Press.

3. Ehrhart, B. (2003). Riparian Areas. Functions and Strategies for Management. Washington, D.C., USA: National Academy Press. Environmental Conservation, 30(04): 408–409.

4. Federal Interagency Stream Restoration Working Group (FISRWG). (1998). Stream Corridor Restoration: Principles, Processes, and Practices. Retrieved from *http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044574.pdf*

5. Goudie, A. S. (Ed.) (2006). Encyclopedia of Geomorphology. New York: Routledge.

6. Hollis, G. E. (1975). The Effect of Urbanization on Floods of Different Recurrence Interval. Water Resources Research, 11(3): 431–435. Retrieved from doi:10.1029/WR011i003p00431.10.1029/WR011i003p00431

7. Leopold, L. B. (1994). A View of the River. Cambridge, MA: Harvard University Press.

8. New York Sea Grant (NYSG). (2015). Coastal Processes and Causes of Shoreline Erosion and Accretion. Retrieved from *http://www.seagrant.sunysb.edu/glcoastal/pdfs/ShorelineErosion.pdf*

9. New York State Department of Environmental Conservation (NYS DEC) Bureau of Habitat. (2006). Shoreline Protection Interpretive Guidance to Staff. Aquatic Habitat Protection Program. Retrieved from *http://www.dec.ny.gov/permits/6042.html*

10. New York State Department of Environmental Conservation (NYS DEC). (2015). New York State Stormwater Management Design Manual. Retrieved from *http://www.dec.ny.gov/docs/water_pdf/swdm2015entire.pdf*

11. Strayer, D. L., & Findlay, S.E.G. (2010). Ecology of Freshwater Shore Zones. Aquatic Sciences, 72: 127–163.

12. Strayer, D., & Tumblety, L. (2015). Managing Shore Zones for Ecological Benefits: Handbook. Staatsburg, NY: Hudson River Sustainable Shorelines Project. Retrieved from *https://www.hrnerr.org/hudson-river-sustainable-shorelines/shorelines-ecology/https://www.hrnerr.org/hudson-river-sustainable-shorelines/shorelines-ecology/*

13. Title 6 of the New York Codes, Rules and Regulations (NYCRR). (1994). Part 608: Use and Protection of Waters (pp. 1).

14. U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). (2007). Part 654 Stream Restoration Design National Engineering Handbook (pp. xxix–xlv). Report No. 210–VI–NEH. Retrieved from *http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/water/manage/restoration/?cid=stelprdb1044707*

15. U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). (1996). Part 650 Engineering Field Handbook, Chapter 16 Streambank and Shoreline Protection. Retrieved from *http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17553.wba*

A.2 – Barrier Island

What is a barrier island?

Barrier islands are sandy, ridge-like, features located parallel to, or in alignment with, the mainland and separated by a shallow sound, bay or lagoon (NPS, 2015). They are typically composed of several natural features, such as beaches, dunes, wetlands and shoals, which can reduce risk (Figure A.2-1, Figure A.2-2). They may form as independent islands separated from the mainland, as elongated spits extending from headlands or across bay mouths. Barrier chains result when an otherwise continuous barrier is interrupted by one or more tidal inlets (USACE, 2009). As their name implies, barrier islands reduce risk by serving as a barrier to waves and surge. They also reduce the velocity of waves and surge. Shoals and beaches on barrier islands supply sediment to other natural features that reduce risk. Barrier islands can also have vegetated features like tidal wetlands and maritime forests that stabilize sediment.

Barrier islands are dynamic land forms that respond to changes in sediment supply, sea level and storm events (Davidson-Arnott, 2010, p. 280, 287). *For this reason, structures or assets sited on coastal barrier islands are considered to be at greater risk.* Natural events, such as waves and storms, may transport sediment offshore, reducing beaches and dunes. Seasonal long period waves tend to restore sand back to the beach. Storms can also erode bluffs or open new tidal inlets. New tidal inlets, or breaches, can impact human development and habitat on the barrier, and have the potential to increase coastal flooding on the mainland. However, inlets also act as a source of sediment for the interior bay and the back side of a barrier (Goudie, 2004; Davidson-Arnott, 2010, p. 287) and can close over time with natural sediment transport (Leatherman and Allen, 1985). Strong storms may also push sand onto the barrier in an "overwash." Overwash transports sediment onto the dune, across the island and in some cases into the back bay, building up the bay side of the island (Goudie, 2004). Dunes provide natural risk reduction by storing sand to resist waves and surge and supply sediment to the beach system.

These natural processes are important to sustaining barrier islands and their regional risk reduction benefits as they evolve over the long term (Davidson-Arnott, 2010, p. 287; Leatherman and Allen, 1985).

Many New York State barrier island shoreline areas are regulated under the Coastal Erosion Hazard Area Act (*http://www.dec.ny.gov/lands/86559.html*). The bay side of barrier islands may include areas regulated as tidal wetlands and identified on Tidal Wetland Regulatory Maps (*http://www.dec.ny.gov/lands/5120.html*). [23]

Credit: © The Nature Conservancy (Matt Levine).

Figure A.2-1. This barrier island in eastern Lake Ontario supports dunes and protects a wetland complex. Denser vegetation forms on the top and landward side of the barrier and holds sand in place.

[23] To determine if a permit is required for a project at a specific location contact the Division of Environmental Permits in the appropriate DEC Regional Office.

Credit: National Park Service.

Figure A.2-2. Aerial view of a new inlet on a barrier island at Fire Island National Seashore, as seen from the Atlantic Ocean to the bay.

How do barrier islands reduce risk?

Barrier islands are typically part of a larger coastal system which may include beaches, dunes, inlets, maritime forests, shoals, nearshore areas and tidal wetlands. Conserving and maintaining this larger natural system reduces risk on and near barrier islands. Risk reduction will vary based on the management of individual natural features. Other measures may be needed to further reduce risks from large surge or flood events.

Barrier islands provide the following risk reduction benefits:

- **Serve as a barrier:** Barrier islands provide a natural barrier that protects bay shorelines from direct ocean waves, surge and currents. However, like many natural features, the level of flood risk reduction afforded by barrier islands depends on barrier island elevation, width, size of adjacent inlets, vulnerability of development and storm characteristics (Grzegorzewski, Cialone, and Wamsley, 2011) and whether natural sediment transport systems can replenish and maintain the barrier as it evolves.
- **Reduce water velocity:** Barrier islands can reduce flooding of the enclosed water body (bay or lagoon) and the mainland (USACE, 2009) primarily by limiting and slowing surge and providing tidal attenuation. Low-level flooding around bay shores is primarily

controlled by how fast water moves through inlets. Deeper inlets with larger cross sections tend to admit more water into back bays.

- **Supply Sediment:** Barriers exchange sand from dunes to the foreshore where it can move alongshore to supply adjacent shoreline areas. Overwash and breaches through barriers can supply sediment to form bay shoals and tidal wetlands. Sediment supply and direction are controlled by the forces of wind, waves and currents.
- **Stabilize soil:** Vegetated dunes, maritime forests and bay side tidal wetlands on barrier islands resist erosion by accumulating vegetation that traps and stabilizes incoming sediment.

Forces and conditions that barriers islands can mitigate to reduce risks to people and communities

- Currents generally parallel to the shoreline causing damage from erosion, floating debris or the mobilization of ice
- Waves, wakes, and surges generally perpendicular to the shoreline causing damage from erosion, floating debris or the mobilization of ice
- Temporarily elevated water levels from surge, high river flows or high lake levels inland of the shoreline causing localized property damage

Human activities that reduce or impair risk-reduction capacity

- Improperly designed erosion management structures (e.g., jetties and groins) can deflect sand past their ends into deeper water, dramatically reducing sediment supply along the shoreline and causing erosion that compromises beaches and barriers. (USACE, 2001; Governor's Coastal Erosion Task Force, 1994)
- Barrier islands can be diminished through the cumulative effects of hard structural measures, which limit sediment movement and increase shoreline erosion in adjacent areas, or the dredging or removal of shoals or ridges that contribute sediment to a barrier island (Dethier et al, 2016; Pilkey et al, 2004). Whenever possible, dredged material should be disposed of within the sediment transport system to minimize these impacts.
- Improper grain size and inadequate amount of placed sand/sediment in beach nourishment projects may reduce the effectiveness of the project.
- Beaches and dunes that are reduced in size following a storm event will provide less protection until the system recovers to its previous state or renourishment is undertaken to rebuild the area to its former level of protection.
- Development sited too close to dunes and beaches can reduce the supply of sediment to beaches and other features that support the barrier island.

- Offshore sand dredging sites, located too close to the shore, can increase wave heights and/or wave focusing that contributes to beach/barrier erosion (USACE, 2001).
- Improper siting of offshore dredging sand sources may reduce sediment supply to adjacent areas and diminish the sand/sediment supplied to the beach leaving the shoreline more susceptible to erosion.
- Excavation or leveling of all of beaches or dunes can accelerate barrier erosion. (Goudie, 2004). Driving or walking over dunes can cause direct erosion and destruction of vegetation that help to capture and accumulate sand and stabilize to dune.
- Infrastructure such as roads and buildings, on a coastal barrier island can prevent natural overwash and wind action that accumulates sand on the island (Leatherman and Allen, 1985)

Other benefits

Barrier islands provide a range of other benefits, including the following:

- **Economic:** Barrier islands provide destinations for recreation and tourism that support the economies of coastal communities.
- **Habitat:** Coastal barriers comprise special habitats hosting unusual ecological communities and species. Examples of rare barrier island species include birds, such as Piping plovers (Charadrius melodus) and plants, such as Seabeach Amaranth (Amaranthus pumilus). The Otis Pike Wilderness Area of Fire Island National Seashore is an example of a unique New York habitat area. Certain ephemeral habitats created by waves and sand movement are unique to coastal barriers.
- **Community, culture, and recreation:** The beaches of coastal barriers are primary recreation opportunities for adjacent communities and visitors. The waters enclosed by barriers host swimming, fishing and shellfishing and many types of recreational boating. Most coastal barriers create unique environments that are essential to local identity.
- **Water filtration/quality:** Beaches on barrier islands sequester and convert nutrients protecting water quality (Bridges et al., 2015).
- **Sequester carbon dioxide:** If the barrier island is vegetated it will sequester carbon dioxide. Vegetation often forms on the protected embayment side of barrier islands and on dunes and maritime forests.

Possible effects of changes in climate and water levels on barrier islands

Sea-level rise/water-level change

- The long term effects of accelerated sea-level rise on coastal barriers in New York are uncertain, however, geologists have established that barrier islands can maintain themselves in response to long term sea-level rise if natural sediment transport processes and sufficient quantities are sustained. (U.S. Climate Change Science Program, 2009). In an unmanaged and undeveloped barrier system, as sediment is washed over to the bay side behind the barrier, it builds a sediment base for tidal wetland vegetation to grow and trap more sediment. The shallower the back-barrier area becomes the faster the potential for the barrier to migrate inland in response to sea-level rise. The barrier will remain in place or build upwards if there is an increased supply of available sediment in the system (Goudie, 2004; USACE, 2009). However, if levels of available sediment in the system remain constant or are reduced, the barrier will tend to migrate towards the mainland and become narrower. This could make the barrier island more vulnerable to erosion and breaching (Ashton et al, 2008). Maximizing available sediment is critical to foster barrier island stability.

Restored barrier island

Restored Natural Barrier Island: In the Northeast, individual features such as beaches and dunes are more likely to be restored to historic conditions, rather than an entire barrier island. However, removal of structures that impede natural sediment transport processes that build and sustain barrier islands can facilitate maintenance and restoration of these systems.

Barrier islands have been created in other parts of the world by connecting existing smaller islands through dredging, filling and stabilizing measures. However, in the Northeast more typically individual features such as restored and nature-based beaches, dunes and shoals are used to stabilize components of an existing barrier island, as opposed to the construction of a new barrier island.

Examples of locations where barrier islands have been restored

- Long Island, NY: Barrier beaches have been artificially nourished or filled along much of the south shore of New York City and Nassau and Suffolk Counties. New York barrier islands that have had beach or dune construction include Coney Island, Rockaway, Long Beach Island, Jones Island and Fire Island. The United States Army Corps of Engineers is partnering with the New York State Department of Environmental Conservation to expedite beach and dune construction on Fire Island in response to strong storms. *http://www.nan.usace.army.mil/Missions/Civil-Works/Projects-in-New-York/Fire-Island-to-Montauk-Point-Reformulation-Study/*
- Jones Beach, NY: Jones Beach State Park and Jones Island which stretches east of the park were the creation of master builder Robert Moses in the 1920s. By dredging sand from what is now the State Boat Channel, Moses raised the elevation of the barrier islands by fourteen feet, connecting several small islands into one long stretch topped by Ocean Parkway. Parts of the coastal barrier at Westhampton Beach have been rebuilt and artificially stabilized with groins.

- ❖ Fire Island, NY: Some areas within the National Park Service's Fire Island National Seashore, including the Fire Island Wilderness area, are mostly unmanaged, and are allowed to function as natural barrier islands. *https://www.nps.gov/fiis/learn/news/final-fire-island-wilderness-breach-management-plan.htm*

Factors to consider in design, construction and maintenance for restoration (if a natural feature)

- ❖ Coastal barrier islands depend upon a wide variety of natural processes to maintain height and width over time. Because barriers are highly dynamic in response to storms and sea level rise, management must be adaptive and flexible to respond to changing conditions.
- ❖ Management of barrier islands often includes artificial fill, which is a limited resource. Relative efficiency and environmental outcomes of active barrier management among other risk management opportunities should be weighed. Development management (elevation, relocation, buyouts) and nourishment projects (beach, dune, wetland and bay shore measures) should be balanced to foster safety and environmental health.
- ❖ Proposals to restore or construct nature-based features that support barrier islands will be more successful if they optimize and maintain the dimensions normally or historically observed at sites over time. Beaches and dunes should be established or nourished with local sediment sources of similar grain size and composition.
- ❖ Consult with the appropriate regulatory agencies before beginning any project near the shoreline of a barrier island.

Sources

1. Aretxabaleta, A. L., Butman, B., & Ganju, N. K. (2014). Water Level Response in Back-Barrier Bays Unchanged Following Hurricane Sandy. Geophysical Research Letters, 41(9): 3163–3172.

2. Ashton, A. D., Donnelley, J. P., & Evans, R. L. (2008). A Discussion of the Potential Impacts of Climate Change on the Shorelines of the Northeastern U.S.A. Mitigation and Adaptation Strategies for Global Change. Springer 13(7): 719–743.

3. Davidson-Arnott, R. (2010). Introduction to Coastal Processes and Geomorphology. New York: Cambridge University Press.

4. Dethier, M. N., Raymond, W. W., McBride, A. N., Toft, J. D., Cordell, J. R., Ogston, A. S., Heerhartz, S. M., Berry, & H. D. (2016). Multiscale Impacts of Armoring on Salish Sea Shorelines: Evidence for Cumulative and Threshold Effects. Estuarine, Coastal and Shelf Science, 175: 106–117

5. Goudie, A. S. (Ed.). (2004). Encyclopedia of Geomorphology (pp. 59–62). New York: Routledge.

6. Governor's Coastal Erosion Task Force. (1994). State of New York.

7. Grzegorzewski, A., Cialone, M., & T. Wamsley. (2011). Interaction of Barrier Islands and Storms: Implications for Flood Risk Reduction in Louisiana and Mississippi. Journal of Coastal Research. Special Issue 59: pp.156-164.

8. Houser, C., et al. (2015). Post-Storm Beach and Dune Recovery: Implications for Barrier Island Resilience. Geomorphology, 234: 54–63.

9. Kraus, N. C., & Wamsley, T.V. (2003). Coastal Barrier Breaching Part 1: Overview of Breaching Processes (No. ERDC/CHL-CHETN-IV-56). Vicksburg, MS: Engineer Research and Development Center, Coastal and Hydraulics Lab.

10. Leatherman, S. P., & Allen, J. R. (1985). Geomorphologic Analysis of South Shore of Long Island Barriers: A Report to the U.S. Army Corps of Engineers, New York District.

11. Morelock, J., Ramirez, W., Hallock, P., Hubbard, D. (2005). Beaches. University of Puerto Rico, Geological Oceanography Program. Retrieved from *http://geology.uprm.edu/Morelock/beachsys.htm*

12. National Park Service (NPS). (2015). Fire Island National Seashore Draft General Management Plan Environmental Impact Statement. Boston, MA: U.S. Department of the Interior, NPS, Northeast Region.

13. New York State (NYS) 2100 Commission. (2013). Recommendations to Improve the Strength and Resilience of the Empire State's Infrastructure. Retrieved from *http://www.governor.ny.gov/sites/governor.ny.gov/files/archive/assets/documents/NYS2100.pdf*

14. New York State (NYS) Sea Level Rise Task Force. (2010). New York State Sea Level Rise Task Force Report to the Legislature. Retrieved from *http://www.dec.ny.gov/docs/administration_pdf/slrtffinalrep.pdf*

15. New York State (NYS) State Parks. (n.d.). Jones Beach State Park. Retrieved from *http://nysparks.com/parks/10/details.aspx*

16. Pilkey, O.H., Neal, W.J. and Bush, D.M. (2004). Coastal Erosion in Isla, F.I., (ed.), Coastal Zones and Estuaries, Coastal Dynamics, Encyclopedia of Life Support Systems (EOLSS). Developed under the Auspices of the UNESCO. EOLSS Publishers. Oxford. UK Retrieved from *http://www.eolss.net*

17. Schwab, W. C., Baldwin, W. E., Hapke, C. J., Lentz, E. E., Gayes, P. T., Denny, J. F., List, J. H., & Warner, J. C. (2013). Geologic Evidence for Onshore Sediment Transport from the

Inner Continental Shelf: Fire Island, New York. Journal of Coastal Research, 29(2): 526–544.

18. Stutz, M. L., & Pilkey, O. H. (2011). Open-Ocean Barrier Islands: Global Influence of Climatic, Oceanographic, and Depositional Settings. Journal of Coastal Research 27(2): 207–222.

19. U.S. Army Corps of Engineers (USACE). (1995). Breach Contingency Plan (p. 10). Retrieved from *http://www.nan.usace.army.mil/Portals/37/docs/civilworks/projects/ny/coast/fimp/0_BCP_Complete_Report.pdf*

20. U.S. Army Corps of Engineers (USACE). (2001). Beach Erosional Hot Spots: Types, Causes, and Solutions (ERDC/CHL CHETN-II-44).

21. U.S. Army Corps of Engineers (USACE). (2009). FIMP: Fire Island Inlet to Montauk Point New York Reformulation Study Draft Formulation Report (pp. 7–8, 36–27, 32).

22. U.S. Army Corps of Engineers (USACE). (2013). Coastal Risk Reduction and Resilience: Using the Full Array of Measures (p. 3). Washington, D.C.: Directorate of Civil Works, USACE.

23. U.S. Army Corps of Engineers (USACE). (2014). Executive Summary, Fire Island Inlet to Moriches Inlet, Fire Island Stabilization Project, Hurricane Sandy Limited Re-evaluation Report. USACE New York District.

24. U.S. Climate Change Science Program. (2009). Synthesis and Assessment Product 4.1, Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region.

25. Valverde, H. R., Trembanis, A. C., and Pilkey, O. H. (1999). Summary of Beach Nourishment Episodes on the East Coast Barrier Islands. Journal of Coastal Research, 15(4): 1100–1118.

A.3 – Beach

What is a beach?

Beaches extend from the top of the upland extent of wave action, often the base of a dune or bluff, to the lowest point of sediment movement in the adjacent waterbody (Davidson-Arnott, 2010, p. 183) (Figure A.3-1 and Figure A.3-2). For the purposes of this guidance, the beach is only the land above mean low water. Underwater land below the low water line is typically considered the nearshore (see also shoal). Beaches reduce risk by reducing the velocity of waves and surge and supplying sediment to other natural features that reduce risk.

Beaches need an adequate and sustained supply of sediment from a variety of sources in order to exist (Figure A.3-3). Beaches are formed and sustained primarily through longshore sediment transport (also called littoral transport), or the movement of sediment along the shoreline. This is also called littoral drift. Wave action can also move sediment onshore from nearshore or shoal areas in calmer conditions and offshore during strong storms, often during the winter months (Davidson-Arnott, 2010, p.148-155; Bridges et al 2015). Beaches also receive sediment from the erosion of updrift features, such as bluffs and dunes, due to wind and wave action. (NAS, 2007; CEHA). During flooding, beaches can change suddenly and significantly due to sediment erosion and deposition as they absorb energy from waves and storms. *For this reason, structures or assets sited on or near beaches are considered to be at greater risk.*

The NYS regulatory definition of a beach is the zone of unconsolidated earth that extends landward from the mean low water line to the seaward toe of a natural protective feature, such as a dune or bluff, whichever is most seaward (Figure A.3-4). Where no dune or bluff exists, the limit of a beach is 100 feet landward from the line of permanent vegetation. Shorelands subject to seasonal or more frequent overwash or inundation are considered beaches (CEHA Reg. 6 NYCRR Part 505.2 (c)). [24]

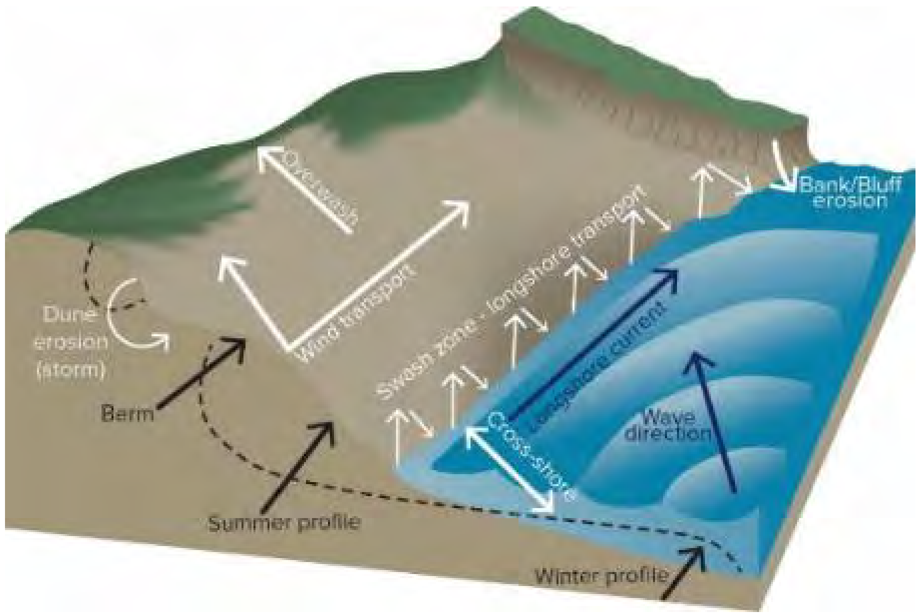
[24] To determine if a permit is required for a project at a specific location contact the Division of Environmental Permits in the appropriate DEC Regional Office.

Credit: © The Nature Conservancy.

Figure A.3-1. A beach in the village of Montauk, Town of East Hampton on the south shore of Suffolk County on Long Island.

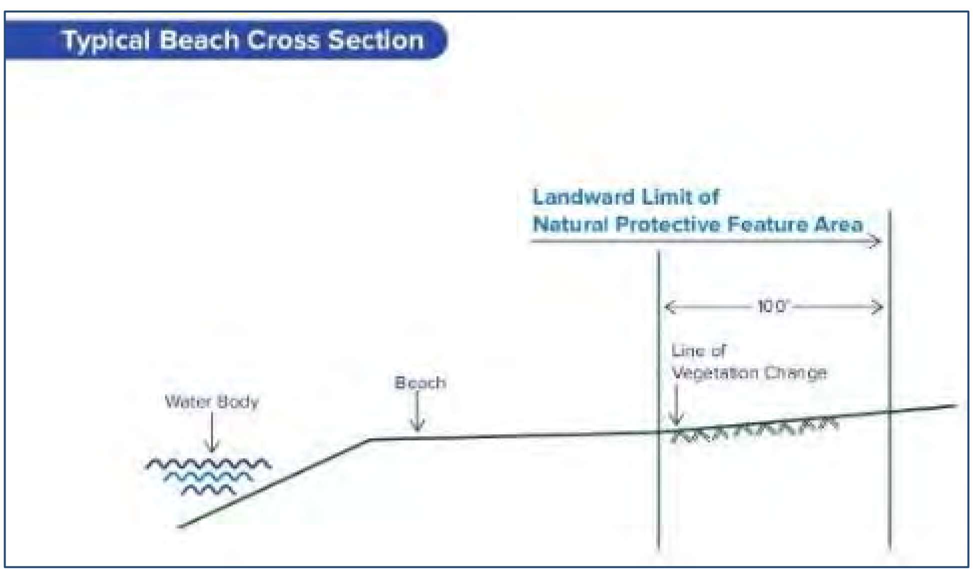
Credit: © The Nature Conservancy.

Figure A.3-2. A vegetated natural beach at Pipes Cove in Southold, NY.



Credit: Greg Berman (2011), Woods Hole Oceanographic Institution Sea Grant & Cape Cod Cooperative Extension.

Figure A.3-3. Sediment moves along the shoreline and off and onshore due to wave, current and wind action.
Sediment movement is indicated by white arrows and water movement is indicated by blue arrows.



Credit: NYS DEC.

Figure A.3-1. Cross-section of a beach highlighting regulatory boundaries.

Figure A.3-4. Eastern Lake Ontario beach impacts after 2017 high lake levels.
Dunes and sand maintain shoreline ecosystem function and structure.

How do beaches reduce risk?

Beaches are part of a larger system which may include barrier islands, bluffs, dunes, nearshore areas and shoals. Conserving and maintaining this larger natural system reduces risk near dunes. Risk reduction will vary based on the management of individual natural features. Other measures may be needed to further reduce risks from large surge or flood events.

Beaches provide the following risk reduction benefits:

- **Reduce water velocity:** Beaches protect shorelines from erosion by breaking and absorbing energy from waves, tides and currents that otherwise would be expended on the toes of bluffs, dunes or inland areas (CEHA).
- **Supply sediment:** Beaches supply sediment to natural features offshore (nearshore sandbars, shoals) and adjacent shoreline areas through longshore sediment transport. During storms offshore areas can serve as sediment supplies for beaches. Beaches can supply sediment to dunes and barrier islands through wind and wave action. (Davidson-Arnott, 2010, p. 228, 280).

Forces and conditions that beaches can mitigate to reduce risks to people and communities

- Currents generally parallel to the shoreline causing damage from erosion, floating debris or the mobilization of ice

- Waves, wakes and surges generally perpendicular to the shoreline causing damage from erosion, floating debris, or the mobilization of ice

Human activities that reduce or impair risk-reduction capacity

- Development sited too close to dunes and beaches can reduce the supply of sediment to beaches and other features.
- The construction of erosion protection structures on beaches that reflect wave energy (e.g., bulkheads, revetments, seawalls) may cause erosion at the toe of the structure, increase erosion in adjacent and nearby areas, and prevent natural processes from maintaining the natural sediment supply.
- Shore perpendicular structures (e.g., groins, jetties) interrupt the natural sediment transport process. They minimizing sediment available to the beach and have the potential to increase erosion downdrift of the structure.
- Improper siting of offshore dredging sand sources may reduce sediment supply to adjacent areas and diminish the sand/sediment supplied to the beach leaving the shoreline more susceptible to erosion.
- Improper grain size and inadequate amount of placed sand/sediment in nourishment projects may reduce the effectiveness of the project.

Other benefits

Beaches provide a range of other benefits, including the following:

- **Economic:** Beaches provide destinations for recreation and tourism that support the economies of coastal communities.
- **Habitat:** Beaches serve as habitat for a variety of invertebrates, shellfish, birds and other wildlife.
- **Community, culture and recreation:** Communities and residents across New York State highly value beaches for scenery and providing access for swimming, walking, fishing and bird watching. Beaches are closely coupled with coastal communities' sense of place and local cultural traditions.
- **Water filtration/quality:** Beaches sequester and convert nutrients protecting water quality (Bridges et al., 2015).

Possible effects of changes in climate and water levels on beaches

Sea-level rise/water level change

- Rising sea levels and may require relocating homes and moving development back from inundated beaches and shorelines to provide enough room for beach restoration and nourishment to reduce risk to neighborhoods. Beach and dune systems will migrate inland in response to sea-level rise in areas where their movement is not restricted by hard structural features and development (Goudie, 2004).

Strong storms

- The availability of sediment affects the adaptability of beaches. If sediment supply is reduced due to hard structural shoreline features, and extreme storm events cause significant erosion, periodic maintenance or nourishment may be required to restore the sediment balance.

Restored or nature-based beach

Restored Natural Beach: A beach can be restored by removing impediments to natural sediment movement, such as groins or jetties. A beach can also be restored by mechanically or hydraulically by placing sediment directly on an eroding shore to restore or form and maintain an adequate recreational beach (USACE, 1984). This is often referred to as beach nourishment or beach fill. The sediment placed on the beach should be compatible material, and of an equivalent or slightly larger grain size. Planting of vegetation on the beach itself may not be feasible due to high energy wave action. Beach restorations may or may not be accompanied by dune work.

Nature-based Beach: A nature-based beach is very similar to a restored beach. It may be paired with other nature-based components like vegetated dunes or berms to meet risk reduction goals. Addition of vegetation to the beach itself may not be feasible due to high energy wave action. Structures such as groins and breakwaters are not considered components of a nature-based beach because of their impact on natural sediment transport, but may be used in conjunction with beach nourishment projects to stabilize the beach and increase the time between necessary renourishment cycles.

Examples of locations where restored or nature-based beaches have been implemented

- Nature-based beaches have been implemented at various locations along the Long Island Sound and Atlantic Ocean coastline of New York State, including Coney Island, Rockaway Beach, and areas of Fire Island through beach nourishment (USACE, 2016).
- Sand bypassing (moving sand from deposition areas to downdrift locations to sustain beaches) has occurred at Shinnecock Inlet, Moriches Inlet, Fire Island Inlet (Tanski, 2007)

and Jones Inlet. Sand backpassing (moving sand from deposition areas back to updrift areas) has occurred at Coney Island (USACE, 2010). http://www.nan.usace.army.mil/Missions/Civil-Works/Projects-in-New-York/

- Homes have been relocated on Fire Island to replenish beach area in response to beach erosion (Figure A.3-5) http://www.nan.usace.army.mil/Missions/Civil-Works/Projects-in-New-York/Fire-Island-to-Montauk-Point-Reformulation-Study/

Credit: US Army Corps of Engineers.

Figure A.3-5. This home, in the Town of Islip on Fire Island, was moved from the top of a fronting dune to a safer location behind the dune in response to repeated flooding and erosion.
Setting development back from beaches and dunes gives them room to move in response to strong storms and sea level rise and can help to reduce flood risk.

Factors to consider in design, construction and maintenance for restoration (if a natural feature) or construction (if a nature-based feature)

- Beaches should be established or nourished with natural local sediment sources of similar grain size and composition. Optimizing and maintaining the dimensions normally or historically observed at the site over time will maximize the beach's ability to reduce risk.

- Restoration should ideally occur where there is minimal encroachment by development and where there is sufficient area to support a beach.

- Hard structures, such as groins and jetties, may interrupt sediment transport and prevent sediment from being transported downdrift, reducing sediment availability and increasing the need for future nourishment. Sand bypassing (moving sand around obstructions to downdrift areas in the littoral system) at maintained inlets may enhance adaptability by restoring sediment transport blocked by jetties and allow sediment to continue being transported downdrift to supply beaches.
- Beaches undergo seasonal profile changes, often having narrower widths in the winter months. This should be a consideration when determining whether periodic nourishment is needed.
- Nourishment projects should be monitored and maintained for effectiveness. Nourishment is a temporary solution to reduce risk and the impacts of nourishment on sediment availability is an active area of study.
- Well-developed berms with adequate height and width should be maintained in order to sustain the beach profile and provide protection of the shoreline from storm surge, sea-level rise and erosion (Bridges et al 2015).
- Beach nourishment projects are typically not as stable over time as natural beaches because the underlying condition that caused the need for nourishment has not been addressed.

Resources

- The U.S. Army Corps of Engineers Coastal Engineering Manual is a primary source of engineering guidance for a variety of shore defenses. Content specific to beach construction is in Part V., Chapter 4: Beach Fill Design (USACE, 2002). *http://www.publications.usace.army.mil/USACE-Publications/Engineer-Manuals/u43544q/636F617374616C20656E67696E656572696E67206D616E75616C/*
- Consult with the appropriate regulatory agencies before beginning any project near a beach.

Sources

1. Berman, G. (2011). Longshore Sediment Transport, Cape Cod, Massachusetts. Woods Hole Sea Grant Program and Barnstable County's Cape Cod Cooperative Extension.
2. Bridges, T. S., Wagner, P. W., Burks-Copes, K. A., Bates, M. E., Collier, Z. A., Fischenich, C. J., ... & Russo, E. J. (2015). Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience (No. ERDC-SR-15-1). Vicksburg, MS: Engineer Research and Development Center, Environmental Lab.
3. Cunniff, N., & Schwartz, A. (2015). Performance of Natural Infrastructure and Nature-Based Measures as Coastal Risk Reduction Features. Environmental Defense Fund.

4. Davidson-Arnott, R. (2010). Introduction to Coastal Processes and Geomorphology. New York: Cambridge University Press.

5. Goudie, A. S. (Ed.). (2004). Encyclopedia of Geomorphology. New York: Routledge.

6. Lancaster, N. (2009). Aeolian Features and Processes (pp. 1–25, Tech.). The Geological Society of America.

7. National Academy of Sciences (NAS). (2007). Mitigating Shore Erosion Along Sheltered Coasts. Committee on Mitigating Shore Erosion along Sheltered Coasts. Ocean Studies Board, Division on Earth and Life Sciences.

8. Tanski, J. (2007). Long Island's Dynamic South Shore — A Primer on the Forces and Trends Shaping Our Coast. New York Sea Grant.

9. Title 6 of the New York Codes, Rules and Regulations (NYCRR). (1988). Part 505: Coastal Erosion Management Regulations (p. 2 and 6).

10. U.S. Army Corp of Engineers (USACE). (1984). Shore Protection Manual Volume I (4th Edition). Washington, D.C.: U.S. Government Printing Office.

11. U.S. Army Corps of Engineers (USACE). (2002). Coastal Engineering Manual Part V. Retrieved from *http://www.publications.usace.army.mil/USACE-Publications/Engineer-Manuals/u43544q/636F617374616C20656E67696E656572696E67206D616E75616C/*

12. U.S. Army Corps of Engineers (USACE). (2010). Atlantic Coast of New York City Rockaway Inlet to Norton Point, Coney Island. Operation, Maintenance, Repair, Replacement and Rehabilitation Manual, Final.

13. U.S. Army Corps of Engineers (USACE). (2013). Coastal Risk Reduction and Resilience. CWTS 2013-3. Washington, D.C.: Directorate of Civil Works, USACE.

14. U.S. Army Corps of Engineers (USACE). (2016). Near-Term Coastal Restoration – FCCE. Retrieved from *http://www.nan.usace.army.mil/About/Hurricane_Sandy/Near-Term-Coastal-Restoration-FCCE/*

15. Woodrow, D., McClennan, C., & Ahrnsbrak, W. (2002). Eastern Lake Ontario Sand Transport Study (ELOSTS): Final Report on Sediment Transport Patterns and Management Implications for Eastern Lake Ontario.

A.4 – Bluff

What is a bluff?

Bluffs are steep shoreline faces, or slopes, typically composed of sands, gravel and/or clays. Some bluffs may include exposed bedrock at or near the surface (Figure A.4-1).

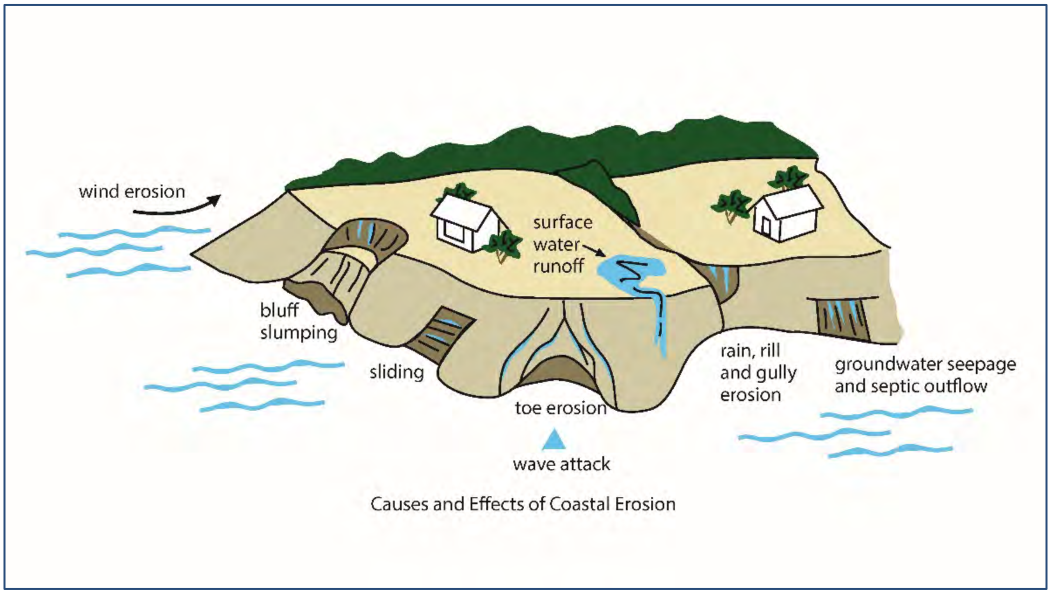
Bluffs provide a source of sediment to beaches, wetlands and nearshore areas. This sediment is necessary to sustain these natural features and their wave attenuation and risk reduction benefits. The growth of healthy vegetation on the top, crest and face of a bluff helps to stabilize the bluff and reduce erosion due to wind and water (NAS, 2007). Bluffs erode at varying rates depending on many site-specific conditions, including soil composition, height, ground water conditions, water levels, slope and wave heights. Bluff erosion may be gradual, or sudden and catastrophic (Figure A.4-2). During high water events or under storm conditions, some bluffs may experience sudden slope failure and rapid loss of material. *For this reason, structures or assets sited near the crest of a bluff are considered to be at greater risk.*

The NYS regulatory definition of a bluff is any bank or cliff with a precipitous or steeply sloped face adjoining a beach or a body of water (Figure A.4-3). Where no beach is present, the seaward limit of a bluff is mean low water and the landward limit is 25 feet landward of the point of inflection on the top of the bluff (6 NYCRR 505, 1988). [25]

Credit: © The Nature Conservancy.

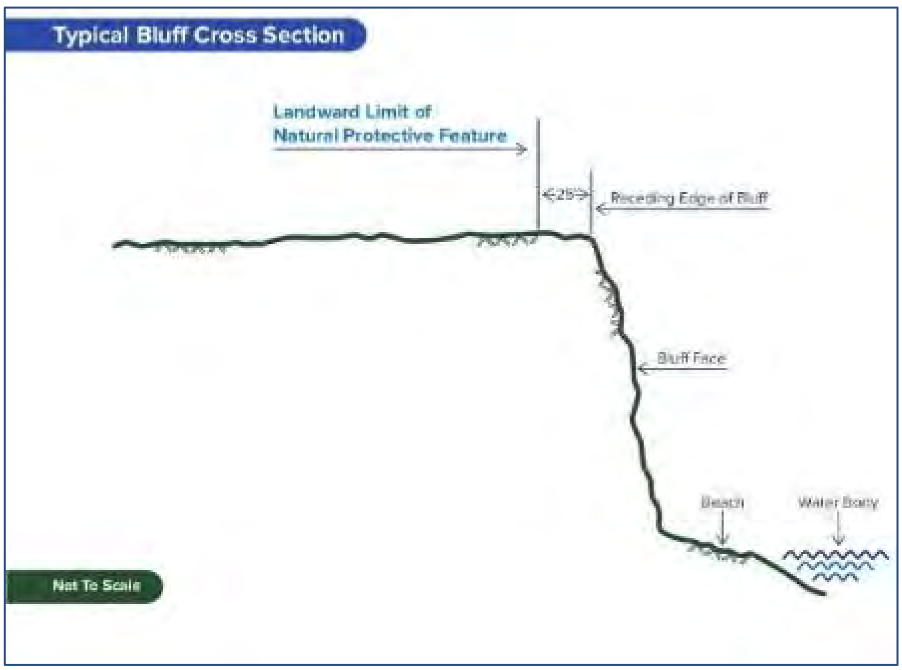
Figure A.4-1. Bluffs along Montauk Beach in Shadmoor State Park on Long Island.

[25] To determine if a permit is required for a project at a specific location contact the Division of Environmental Permits in the appropriate DEC Regional Office.



Credit: Amy Kittleson, Wisconsin Sea Grant (2003).

Figure A.4-2. Coastal bluff erosion occurs through a variety of processes.



Credit: NYS DEC.

Figure A.4-3. Typical bluff cross section with bluff features and regulatory boundaries.

How do bluffs reduce risk?

Bluffs are typically part of a larger coastal system which may include beaches, dunes, nearshore areas and shoals. Conserving and maintaining this larger natural system reduces risk near bluffs. Risk reduction will vary based on the management of individual natural features. Other measures may be needed to further reduce risks from large surge or flood events.

Bluffs provide the following risk reduction benefits:

- **Serve as a barrier:** Bluffs absorb energy from waves and tides. The elevation of a bluff creates a physical barrier which reduces the impacts of storm surge and flooding to upland areas (NAS, 2007). Bedrock bluffs mitigate erosion caused by current, wave or wake energy because of their strength (Davidson-Arnott, 2010).
- **Reduce water velocity:** If bluffs are overtopped they still attenuate wave energy minimizing the effects of flooding to upland areas (6 NYCRR 505, 1988; NAS, 2007).
- **Supply sediment:** Bluffs contribute sediment that builds beaches, wetlands and shoals. These features dissipate energy from waves, tides, surge and currents. In stream systems bluff sediment may be transported by currents to such as shoals and tidal wetlands.

Forces and conditions that bluffs can mitigate to reduce risks to people and communities

- Waves, wakes and surges generally perpendicular to the shoreline causing damage from erosion, floating debris or the mobilization of ice
- Temporarily elevated water levels from surge, high river flows or high lake levels inland of the shoreline causing localized property damage

Human activities that reduce or impair risk-reduction capacity

- Development sited too close to bluff systems may cause an increase in erosion to the bluff because of increased saturation and runoff from sources such as septic system leachate.
- Hard structures that seek to stabilize bluffs are likely to reduce the supply of sediment available to natural protective features such as beaches, shoals and wetlands .
- Excavation of the bluff crest, face, or toe will reduce the elevation of the bluff and may reduce the supply of sediment available to the fronting beach.
- Groundwater seepage/drainage, or stormwater runoff over the bluff face may cause erosion and a reduction in elevation.
- Removal of vegetation on the topland, bluff crest and bluff face will increase the potential for bluff erosion and impact habitat.

- Activities that result in the loss of a beach in front of the bluff (e.g., improperly designed and/or constructed erosion management structures, disruption in the supply of sediment to the beach, etc.) may cause increased erosion of the bluff toe and greater instability of the bluff.

Credit: NYS DEC.

Figure A.4-4. Bluff erosion and collapse along the shoreline of Lake Ontario. Development sited close to the crest or edge of a bluff can be more vulnerable to collapse, especially in strong storms.

Other benefits

Bluffs provide a range of other benefits, including the following:

- **Economic:** Dramatic bluffs and beaches provide destinations for recreation and tourism that support the economies of coastal communities (Bridges et al., 2015; NAS, 2007)
- **Habitat:** Bluffs may provide cover for terrestrial organisms and secure nesting sites and hunting perches for birds. Overhanging vegetation can provide habitat value and shade beaches and nearshore areas. Unvegetated and rocky bluffs may provide habitat for

ledge-dwelling birds (NAS, 2007). Bluffs can be important resting and feeding areas for migrating birds (e.g., Derby Hill, Oswego County).

- **Community, culture and recreation:** Communities value bluffs for scenery, access and wildlife-related recreation, especially in combination with a beach (NAS, 2007). Large steep bluffs, such as ones found off Montauk Point, NY and along Lake Ontario, add to the value and identity of the community.
- **Sequester carbon dioxide:** Vegetated bluffs sequester carbon dioxide.

Possible effects of changes in climate and water levels on bluffs

Sea-level rise/water level change and stronger storms

- Rising sea levels, changes in lake levels and stronger storms may require relocating homes and development back from eroding bluffs to provide enough room for bluffs and beaches to absorb wave energy.
- Bluffs that are tall and long can provide protection against higher water levels caused by sea-level rise or storm surge. Smaller bluffs or banks have a greater chance of being eroded or overtopped during storm events.

Restored or nature-based bluff

Restored Natural Bluff: A bluff can be restored by removing hard structural features to restore natural sediment transport processes. Native vegetation may be planted to stabilize areas of the bluff face.

Nature-based Bluff: Nature-based coastal techniques including sloping, revegetating and terracing, can be used to reduce erosion from the face and the toe of the bluff. Constructed stormwater green infrastructure techniques can be used to intercept stormwater to prevent it from flowing down the face of a bluff where is can cause erosion.

Credit: S. Masullo, Goldberg and Rodler, Inc.

Figure A.4-5. In response to erosion impacts from Hurricane Sandy, this bluff in Orient Point was stabilized using several layers of jute matting and native seaside plants, such as American Beach Grass and Bayberry, were planted on the crest and slope.
A small berm was added to the crest of the bluff to prevent stormwater running down the slope and minimize erosion. Temporary irrigation was used to ensure the plants became established. As the plants grow, they will provide coastal habitat and absorb greenhouse gases, while their root systems will hold the slope in place. Credit: S. Masullo, Goldberg and Rodler, Inc.

Examples of locations where restored or nature-based bluffs have been implemented

- Lake Ontario and Lake Erie, NY: Projects to create nature-based bluffs, through revegetating, terracing, stabilizing and sloping, have taken place on Lake Ontario and Lake Erie coastline of New York State.
- Long Island, NY: Nature-based bluff projects have been implemented in a variety of locations on Long Island including Glen Cove, Montauk Point, Southold, East Hampton and Orient Point (Figure A.4-5).
- South Haven, MI: Lake Michigan Bluff Stabilization Project *http://www.prestogeo.com/downloads/cvpGYBC6EZp9RkCIWzRAiA2dtEF0ZiuFoIGqELGtKXBuaK4w0K/Lake_Michigan_Shoreline_Geoweb-TRM.pdf*.

- Lake Ontario and Long Island, NY: Homes have been relocated from rapidly eroding bluffs near Sodus Point, along the shoreline of Lake Ontario, and on Long Island. (Figure A.4-6).

Credit: Wolfe House and Building Movers.

Figure A.4-6. This large structure on Fishers Island, off the tip of Long Island, was relocated away from an eroding bluff.

Factors to consider in design, construction and maintenance for restoration (if a natural feature) or construction (if a nature-based feature)

- Maintaining a stable angle of repose, keeping the slope vegetated with native species and preventing runoff over the bluff face are all important factors in minimizing bluff erosion. Drainage from all areas of the property should be designed to minimize runoff over the bluff face. Vegetation on the bluff should be deep rooted and suitable to the local climate to maximize its effectiveness.

- Bluff erosion often occurs due to a number of factors, including surface water runoff, ground water seepage, wave attack and ice damage. Maintaining the optimal dimensions of a fronting beach will help to lessen the effects of erosion on the bluff toe and provide greater stability of the bluff.
- Development along bluffs should be sited far enough back from the receding edge to allow for a reasonable probability of survival over the project's design life.
- While bluffs offer protection from high water, in many areas of New York State they also experience significant natural erosion. Periodic bluff recession is normal, but could be minimized by maintaining healthy vegetative cover. Proper siting of development set back from the crest of a bluff is key to protecting private property and public infrastructure over the long term.

Resources

- The NOAA Great Lakes Coastal Resilience Planning Guide (ASFPM and NOAA, n.d.) contains good information on managing bluffs to reduce risk at *http://greatlakesresilience.org/case-studies/land-use-zoning/minimizing-bluff-top-development-risk*.
- The State of Pennsylvania has prepared a guidance document on bluff behavior and regulatory standards that includes helpful information on erosion, sediment processes and effects of structural measures (Pennsylvania DEP, 2013). It is available at *http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-94560/394-2000-001.pdf*.
- The Green Shores for Homes (2016) program, funded by the EPA and developed by the City of Seattle, provides guidance on shoreline restoration measures, including a point-rating system for shoreline management alternatives that can be used on a community or basin-wide basis. It can be found at *http://greenshoresforhomes.org/*.
- Consult with the appropriate regulatory agencies before beginning any project near a bluff.

Sources

1. Association of State Floodplain Managers (ASFPM) and National Oceanic and Atmospheric Administration (NOAA). n.d. Great Lakes Coastal Resilience Planning Guide. Retrieved from *http://www.greatlakesresilience.org/*

2. Bridges, T. S., Wagner, P. W., Burks-Copes, K. A., Bates, M. E., Collier, Z. A., Fischenich, C. J., ... & Russo, E. J. (2015). Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience (No. ERDC-SR-15-1). Vicksburg, MS: Engineer Research and Development Center, Environmental Lab.

3. Buonaiuto, F. S., and Bocuniewicz, H. (2005). Coastal Bluff Recession and Impacts on Littoral Transport, Special Reference to Montauk, NY, Shore and Beach (p. 24–29).

4. Davidson-Arnott, R. (2010). An Introduction to Coastal Processes and Geomorphology. New York: Cambridge University Press.

5. Goudie, A. S. (Ed.). (2004). Encyclopedia of Geomorphology. New York: Routledge.

6. Green Shores for Homes. (2016). Washington Sea Grant, City of Seattle, San Juan County (WA), Stewardship Center for British Columbia, Islands Trust of British Columbia. Retrieved from *http://greenshoresforhomes.org/*

7. Isachsen, Y. W., et al. (2000). Geology of New York: A Simplified Account (Chapters 7 and 10). Albany, NY: The New York State Education Department, The New York State Geological Survey.

8. National Academy of Sciences (NAS). (2007). Mitigating Shore Erosion Along Sheltered Coasts. Committee on Mitigating Shore Erosion along Sheltered Coasts. Ocean Studies Board, Division on Earth and Life Sciences.

9. Pennsylvania Department of Environmental Protection (DEP). (2013). Municipal Reference Document: Guidance for the Implementation of the Chapter 85 Bluff Recession and Setback Regulations 394-2000-001. Interstate Waters Office, Coastal Resources Management Program. Retrieved from *http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-94560/394-2000-001.pdf*

10. Title 6 of the New York Codes, Rules and Regulations (NYCRR). (1988). Part 505: Coastal Erosion Management Regulations (p. 2 and 7).

11. U.S. Army Corps of Engineers (USACE) and University of Wisconsin Sea Grant. (2003). Living on the Coast: Protecting Investments in Shore Property on the Great Lakes. Retrieved from *http://www.lre.usace.army.mil/Missions/Great-Lakes-Information/Coastal-Program/Coastal-Processes/*

A.5 – Dune

What is a dune?

A dune is an active accumulation of sand, formed primarily by wind action, with some elevation. Dunes can occur on a beach or further inland (CMECS, 2012). Dunes reduce risk by serving as a barrier and reducing water velocity and supplying sediment to other natural features that reduce risk. Vegetated dunes also stabilize sediment.

Wind action can move sediment from beaches inland to form and sustain a dune. Dunes may supply sand/sediment back to a beach by wave action during storm events. This can widen the beach, which may reduce wave action on the dune and continue the supply of sand from the beach to the dune (Davidson-Arnott, 2010). Healthy dune vegetation traps wind-driven sand, increasing dune size (Figure A.5-1). Sand and/or sediment may be eroded from a beach or dune during strong storms, but large swell waves and onshore winds can return this sand over time, rebuilding the dune (Figure A.5-2). Dunes are likely to move or change suddenly and significantly as they absorb energy from waves and storms. *For this reason, structures or assets sited in front of, on or near dunes are considered to be at greater risk.*

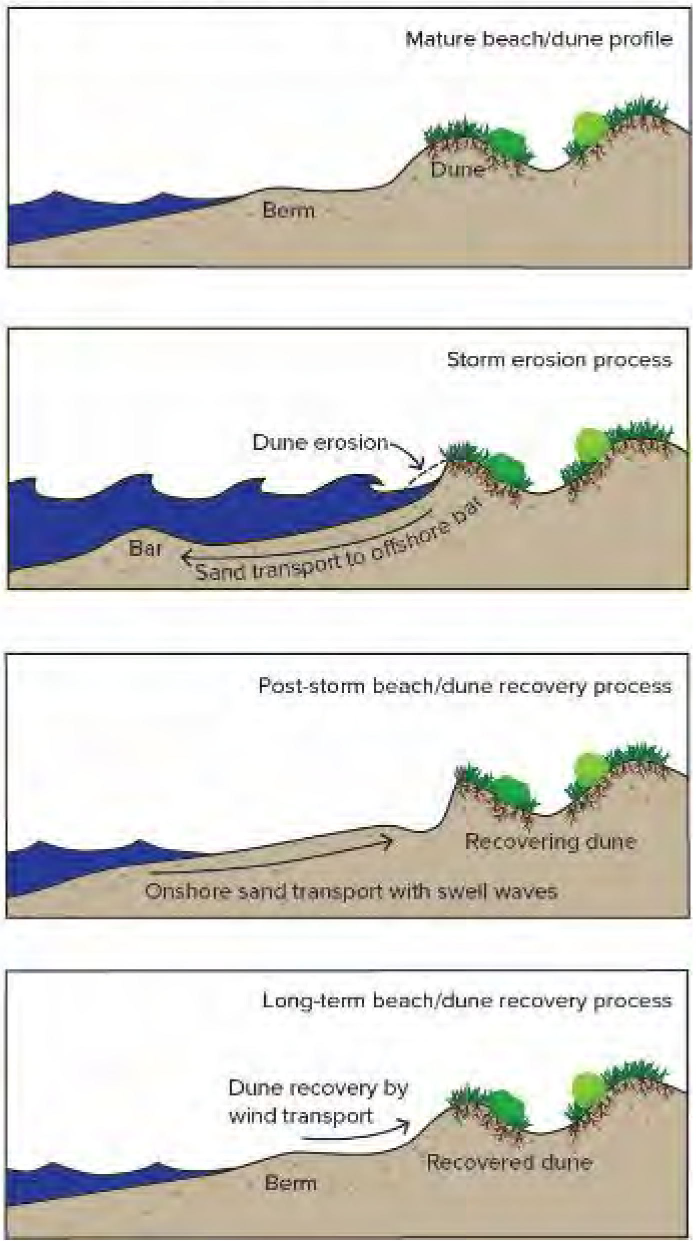
The NYS regulatory definition of a dune is a ridge or hill of loose, windblown, or artificially placed sand and its vegetation. The primary dune in state regulations extends from the edge of its connecting beach, to 25 feet landward from the landward toe of the dune (6 NYCRR 505, 1988) (Figure A.5-3). [26]

[26] To determine if a permit is required for a project at a specific location contact the Division of Environmental Permits in the appropriate DEC Regional Office.

Credit: NYS DOS.

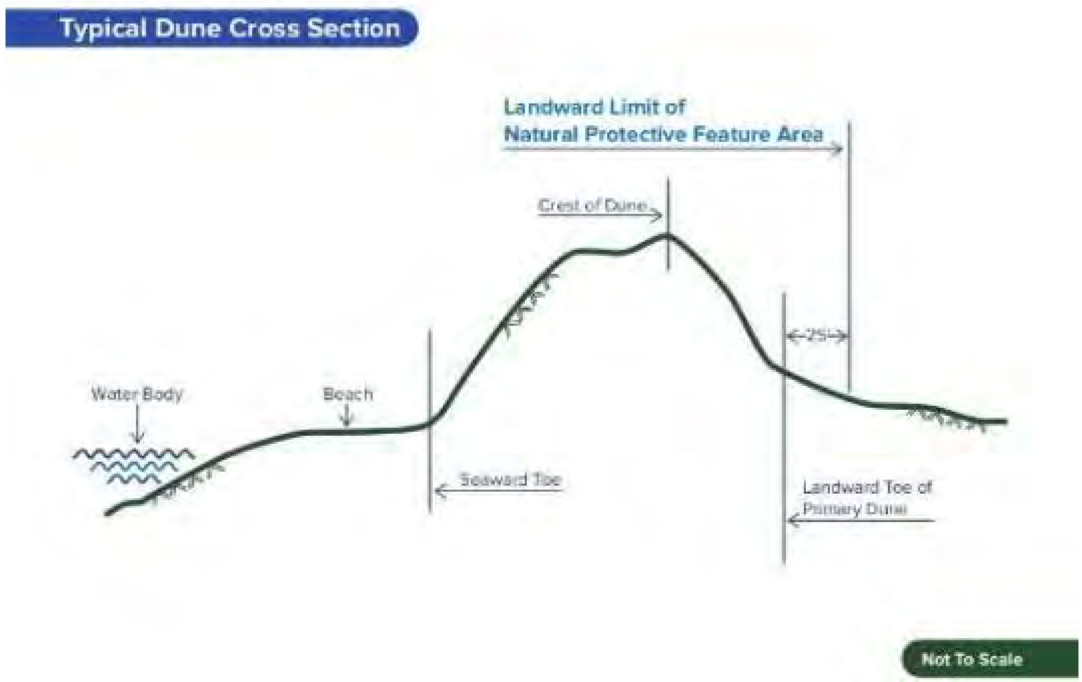
Figure A.5-1. Natural vegetated dune system at Robert Moses State Park in Suffolk County, NY.

Beach/Dune Lifecycle



Credit: NYS DEC.

Figure A.5-2. **Dunes are constantly evolving. Sand and/or sediment may be eroded from a beach or dune during strong storms, but large swell waves and onshore winds can return this sand over time, rebuilding the dune.**



Credit: NYS DEC.

Figure A.5-3. Illustration of typical dune features and state regulatory boundaries.

Credit: E. Sheridan.

Figure A.5-4. Sand fencing and vegetation used to stabilize Southwick Beach in Jefferson County, NY.

Credit: NYS DOS.

Figure A.5-5. This artificially constructed nature-based dune on Long Island includes planted dune grass and sand fencing to capture and retain sand.

How do dunes reduce risk?

Dunes are part of a larger coastal system which may include barrier islands, beaches, bluffs, nearshore areas and shoals. Conserving and maintaining this larger natural system reduces risk near dunes. Risk reduction will vary based on the management of individual natural features. Other measures may be needed to further reduce risks from large surge or flood events.

Dunes reduce risk by providing the following risk reduction benefits:

- **Serve as a barrier:** Dunes physically intercept water which helps to reduce the risk from flooding, storm surge and wave overtopping. (Bridges et al, 2015).
- **Reduce water velocity:** Dunes and their vegetation create friction that slows and absorbs energy from large waves and surge.
- **Supply sediment:** Dunes act as a reservoir of sediment to support formation of beaches and shoals. During storm events dune erosion provides sediment to adjacent features. During mild weather, wind-blown sand from adjacent features accumulates in the dunes.

- **Stabilize sediment:** Healthy vegetation, like grasses and shrubs, on a dune provides stability and allows for accretion of sand/sediment that further reduces risks from wave energy, erosion, flooding and storm surge on the landward side of the dune system. If a dune is stable for long enough, shrub vegetation and eventually maritime forest will form on its landward side. If sediment supplies are sufficient, dunes will grow forward toward the beach.

Forces and conditions that dunes can mitigate to reduce risks to people and communities

- Waves, wakes and surges generally perpendicular to the shoreline causing damage from erosion, floating debris, or the mobilization of ice
- Temporarily elevated water levels from surge, high river flows, or high lake levels inland of the shoreline causing localized property damage

Human activities that reduce or impair risk-reduction capacity

- Excavation and construction of structures that require clearing of vegetation and cutting into the dune and structures that impede vegetative growth or sand movement directly and indirectly on to the beach compromise dunes (Figure A.5-6).
- Development sited too close to dune systems can reduce the size and effectiveness of the dune to serve as a natural barrier (or remove a dune entirely) allowing water to move around and through the dune. It can also prevent dune migration and reduce the supply of sediment to the dune or from the dune to adjacent beaches and other features.
- Removal of sand from the beach reduces the sediment supply to the dune which can reduce the size, structure and effectiveness of the dune to serve as a natural barrier.
- Shore perpendicular structures such as groins or jetties can interrupt longshore sediment transport and increase erosion on the downdrift side of the structure. This reduces supplies of sand/sediment available to the downdrift beaches for dune building and stabilization.
- Use of improper grain size and/or inadequate amount of placed sand/sediment in beach nourishment projects can lead to beach erosion, reducing the size and effectiveness of the beach to supply sediment to the dune and adjacent areas.
- Driving and walking on dunes can disturb or remove vegetation and destabilize a dune. This in turn reduces the ability of the dune to resist surge and reduces sand/sediment supply to adjacent beaches and shoals from the dune.
- Offshore or updrift dredging of sand sources can reduce sediment supply to the beach which may in turn reduce the supply of sediment to the dune.

Credit: NYS DOS.

Figure A.5-6. House constructed within a dune system on Fire Island, NY.
Siting homes and other structures on or too close to a dune limits their ability to reduce risk by removing vegetation that holds the dune together. It also creates pathways for water to move around and through the dune.

Other benefits

- **Economic:** Dunes and their associated beaches provide destinations for recreation and tourism that support the economies of coastal communities (Bridges et al, 2015).
- **Habitat:** Dunes provide habitat for a range of plants and grasses (e.g., American beachgrass, dune willow), provide refuge areas for small mammals such as rabbits and small rodents, basking habitat for turtles and provide nesting sites and corridors for migrating species. (NAS, 2007).
- **Community, culture and recreation:** Communities value healthy dune systems for scenery and wildlife related recreation, especially in combination with a beach.

- ➔ **Water filtration/quality:** Dune vegetation and the sand itself can filter water, saltwater intrusion into coastal aquifers and remove excess nutrients. (Davidson-Arnott, 2010).
- ➔ **Carbon sequestration:** Dune vegetation sequesters carbon dioxide. Where dunes protect wetlands, they help secure those features, which in turn provide significant carbon storage capacity.

Possible effects of changes in climate and water levels on dunes

Sea-level rise/water level change

- Natural dunes have the capacity to adapt to higher water levels if they have an adequate supply of sediment (Cunniff and Schwartz, 2015). Beach and dune systems will migrate inland in response to sea-level rise in areas where their movement is not restricted by hard structural features and development (Goudie, 2004). Minimizing the disruption of sediment transport, keeping human activities on or near the dune to a minimum and avoiding loss of sediment supply due to nearshore dredging or shoreline armoring will help dunes adapt naturally as sea levels rise or lake water levels change.
- Rising sea levels and stronger storms may require relocating homes and moving development back from dunes to provide enough room for dune and beach migration.

Stronger Storms

- Dunes (and beaches) have the natural ability to recover after the stormy winter season as calmer conditions and longer swell waves bring sediment from the nearshore to the beach. This, in turn supplies sand to build up the dune system.

Restored or nature-based dune

Restored Natural Dune: A dune can be restored by planting or re-planting native vegetation (e.g., American beachgrass), removal of invasive or non-native plant species and/or the installation of semi-permeable sand fencing to allow for the entrapment of sand/sediment and natural restoration to occur (Figure 3). Increasing sand supplies on adjacent beaches by beach construction, sand bypassing or restoration of longshore sediment transport tends to make more sand available for wind-driven transport, which can help build dunes. Dunes and their stabilizing vegetation can also be protected by preventing foot and vehicle traffic or providing boardwalk and walkover structures where public access is needed. (NYS DEC, 2007).

Nature-based Dune: An artificially constructed and vegetated sand ridge in a shore- parallel orientation that emulates the location and dimensional relationship of a natural dune to the fronting beach, would be a nature-based dune (Figure A.5-4).

Examples of locations where restored or nature-based dunes have been implemented

- Long Island, NY: Dune systems in Rockaway Beach, Fire Island, Lido Beach, Point Lookout and West of Shinnecock Inlet have all been restored through the Long Island Sound Coastal Management Program (NYS DOS, 1999). *https://www.dos.ny.gov/opd/programs/WFRevitalization/longisland.html*
- Lake Ontario, NY: Dune and wetland protection and restoration have been done on eastern Lake Ontario (Figure A.5-7) *http://www.seagrant.sunysb.edu/elodune/default.html*

Credit: © The Nature Conservancy (Matt Levine).

Figure A.5-7. Dune and wetland complex on the shoreline of Eastern Lake Ontario.

Factors to consider in design, construction and maintenance for restoration (if a natural feature) or construction (if a nature-based feature)

- Dunes should be restored on beaches that have sufficient sediment supply and natural local sediment sources of similar grain size and composition (Cunniff and Schwartz, 2015). In addition, restoration of dunes should ideally occur where there is minimal encroachment by development and where there is sufficient beach area to place the dunes appropriately above the spring high tide line.
- Design and engineering should consider the dune height, width and crest, beach slope, sediment grain size and supply, beach length, berm height and width and likelihood of success given proximity to development.
- The dune volume, height, location, position on the beach and foreshore slope must be consider prevailing wave heights and the effects of periodic storms to foster natural processes that sustain dunes. Optimizing and maintaining the dimensions normally or historically observed in the vicinity over time will maximize the dune's ability to reduce risk. Trapezoidal or flat topped dunes are more effective than round topped dunes, which have less area for vegetation (Cunniff and Schwartz, 2015).
- Well-developed beach berms with adequate height and width should be maintained in order to sustain the beach profile and continue the supply of sand/sediment to the dune.
- Planting dune grasses fosters sand accumulation and stabilizes the dune. Successful dune building primarily depends on the plant/vegetation density, height and cover, wind velocity and rates of sand transport and supply (Goudie, 2004). A dune's ability to sequester nutrients and provide habitat for wildlife is limited until vegetation is fully established (Cunniff and Schwartz, 2015). Native vegetation, such as American Beach Grass, is preferred. Sand fencing and vegetation enhance the ability of the dune to capture and retain sediment.
- Conserving undeveloped areas inland of the dune will allow dunes to migrate inland over time in response to strong storms and sea-level rise and continue to provide their protective functions.
- Similar to beaches, periodic re-nourishment and/or maintenance of sand may be used to augment dunes following erosion and damage from storm events. Sand fencing can be used to encourage the deposition of windblown sand and protect vegetation, supporting dune growth.

Resources

- The U.S. Army Corps of Engineers Coastal Engineering Manual is a primary source of engineering guidance for a variety of shore defenses. Content specific to dunes is in Part V. http://www.publications.usace.army.mil/USACE-Publications/Engineer-Manuals/u43544q/636F617374616C20656E67696E656572696E67206D616E75616C/

- Consult the appropriate regulatory agencies before beginning any project near a dune.

Sources

1. Bridges, T. S., Wagner, P. W., Burks-Copes, K. A., Bates, M. E., Collier, Z. A., Fischenich, C. J., ... & Russo, E. J. (2015). Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience (No. ERDC-SR-15-1). Vicksburg, MS: Engineer Research and Development Center, Environmental Lab.

2. Coastal and Marine Ecological Classification Standard (CMECS). (2012). Marine and Coastal Spatial Data Subcommittee, Federal Geographic Data Committee (p. 72).

3. Cunniff, S., & Schwartz, A. (2015). Performance of Natural Infrastructure and Nature-Based Measures as Coastal Risk Reduction Features. Environmental Defense Fund.

4. Davidson-Arnott, R. (2010). Introduction to Coastal Processes and Geomorphology. New York: Cambridge University Press.

5. Goudie, A. S. (Ed.). (2004). Barrier and Barrier Island, Coastal Sand Dunes. Encyclopedia of Geomorphology. New York: Routledge.

6. National Academy of Sciences (NAS). (2007). Mitigating Shore Erosion Along Sheltered Coasts. Committee on Mitigating Shore Erosion along Sheltered Coasts. Ocean Studies Board, Division on Earth and Life Sciences.

7. New York Sea Grant. (n.d.). Eastern Lake Ontario Dunes and Wetlands. Interpretive Panels. Retrieved from *http://www.seagrant.sunysb.edu/elodune//Education/Interppanels.html*

8. New York State Department of Environmental Conservation (NYS DEC). (2007). Natural Heritage Area Designation for Eastern Lake Ontario. Retrieved from *http://www.dec.ny.gov/animals/38944.html*

9. New York State Department of State (NYS DOS). (1999). Long Island Sound Coastal Management Program. Retrieved from *https://www.dos.ny.gov/opd/programs/WFRevitalization/longisland.html*

10. New York State Department of State (NYS DOS). (2007). New York's Eastern Lake Ontario Dune and Wetland System: Guidelines for Resource Management in the 21st Century. Retrieved from *https://www.dos.ny.gov/opd/programs/pdfs/Guidebooks/LakeOntarioDune.pdf*.

11. Title 6 of the New York Codes, Rules and Regulations (NYCRR). (1988). Part 505: Coastal Erosion Management Regulations (p. 2 and 7).

12. U.S. Army Corps of Engineers (USACE). (2013). Coastal Risk Reduction and Resilience. CWTS 2013-3. Washington, D.C.: Directorate of Civil Works, USACE.

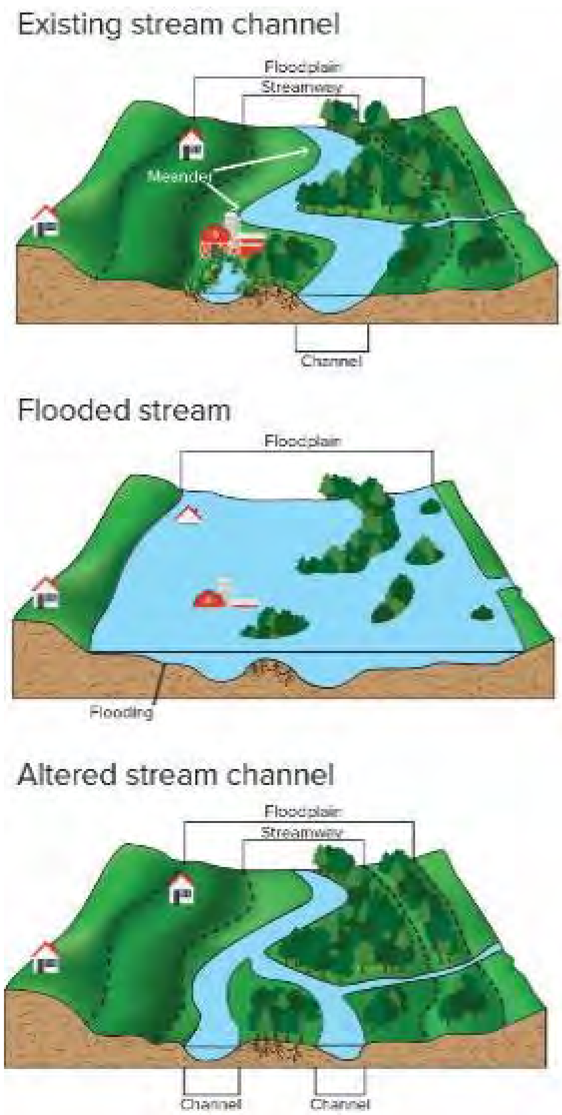
A.6 – Floodplain

What is a floodplain?

A floodplain or flood-prone area is any land area susceptible to being inundated by water from any source (FEMA, 2000). Floodplains extend upland from river, stream, lake, estuary and ocean shorelines, irrespective of whether they are natural or developed (Figure A.6-1). Flooding frequency varies from location to location.

Riverine floodplains are formed through a process of sediment transport and deposition. As a result of this process, river channels curve or bend side-to-side in the streamway, forming meanders and widening the valley. These two processes continually modify the floodplain. Overtime the stream can reshape and transform the entire valley floor. Coastal floodplains are formed by similar processes. Seasonal variability, constant wave action and intermittent extreme events deposit and erode sediments and reshape coastal floodplain channels and inlets. During floods, floodplains allow water to spread out and slow down, reducing risk to adjacent development. Flooding from hurricanes and storms increases soil fertility, creates or reshapes wetlands, barrier islands and dunes (Association of State Floodplain Managers, 2008). Regulatory definitions and maps of areas in floodplains that flood with specific frequencies (i.e. 1% annual chance flood) are developed and managed by the Federal Emergency Management Agency (*https://www.FEMA.gov*).

Floodwater levels in floodplains can change suddenly and significantly in strong storms. Floodplains can also change over time as they absorb energy from currents, waves and storms. *For this reason, structures or assets sited in or near floodplains are considered to be at greater risk.*



Credit: NYS DEC.

Figure A.6-1. This set of illustrations show the stream channel, floodplain, meander and streamway and how they can change during a flood.
The middle diagram illustrates how water fills the floodplain during a flood. In flood conditions, the stream can move within the streamway and damage structures sited too close to the stream. The bottom diagram illustrates how the stream channel has split and moved as a result of the flood.

Credit: © The Nature Conservancy.

Figure A.6-2. Development near the Wading River in Suffolk County, NY. Coastal flooding in this location during high tide has increased over time due to sea-level rise

How do floodplains reduce risk?

Floodplains are part of a larger natural system which can include streams, riparian areas, banks, tidal and non-tidal wetlands, forests and maritime forests. Conserving this larger natural system reduces risk in the floodplain. Risk reduction will vary based on management of these individual features. Other measures may be needed to further reduce risk from large surge or flood events.

Floodplains provide the following risk reduction benefits:

- **Reduce water velocity:** Undeveloped floodplains allow concentrated flows coming from either the land or waterbody to slow down and spread out (Figure A.6-4). This reduces sheer stress both on the shoreline and flood prone areas, reducing risk of erosion to stream and riverbanks. Floodplain vegetation creates friction that dissipates currents, wave action and storm surge.

- **Absorb water:** As water slows and spreads out in floodplain areas, it infiltrates into the ground, especially in areas without significant paved or impervious surfaces. Plants also contribute to organic matter that absorbs water and helps to maintain good porous soil (Hoorman and McCutcheon, 2005).
- **Convey water:** During high flow events, undeveloped floodplains convey water away from the main waterbody providing natural flood storage to be slowly released overtime.

Credit: NYS DEC.

Figure A.6-3. Winter flooding in the Wallkill River outside of New Paltz, NY.
Ice in the main channel is flowing left to right in the foreground, while water in the background is slowing and being stored in the floodplain, preventing more damaging flooding downstream

Forces and conditions that floodplains can mitigate to reduce risks to people and communities

- Currents generally parallel to the shoreline causing damage from erosion, floating debris or the mobilization of ice
- Waves, wakes and surges generally perpendicular to the shoreline causing damage from erosion, floating debris or the mobilization of ice

- Precipitation or meltwater moving downhill to nearest waterbody causing erosion, temporary pooling and localized water damage
- Temporarily elevated water levels from surge, high river flows or high lake levels inland of the shoreline causing localized water damage

Human activities that reduce or impair risk-reduction capacity

- Reduction of floodplain area due to development and fill in the floodplain reduce the floodplain's capacity to pass, store and absorb floodwaters resulting in increased water velocity and erosion.
- Changes in floodplain shape and function can limit the area available for the migration of streams and coastal features, increase flood water velocity by restricting flows and reduce the area available for sediment deposition.
- Flood protection structures, such as levees, dams, berms and fragmentation of floodplains by infrastructure (e.g., roads, bridges, culverts and rail lines) can restrict flow of floodwaters into and out of floodplains.
- Land use changes in the watershed and floodplain, such as an increase in impervious surfaces, drainage ditches and stormwater piping, that move water into receiving water bodies more quickly instead of letting water infiltrate into the ground, can increase the magnitude and energy of flood flows in the stream or river and increase erosion (Hollis, 1975; Ehrhart, 2003; Chemung County SWCD, 2006; NYS DEC, 2015).
- Removal of floodplain vegetation can increase water velocity in receiving water bodies.

Other benefits

Floodplains provide a range of other benefits, including the following:

- **Economic:** Property loss can be prevented by regulating development in riparian floodplains. In one study, researchers estimated that over a 50-year timeframe, the cost of permanent floodplain conservation through riparian easements saved $85,000/mile compared to the cost of repeated streambank armoring in the same area (Kline, 2008). Undeveloped riparian floodplains provide economic benefits to public water by recharging aquifers and protecting water quality through filtration of runoff and sedimentation (Fischer and Fishenech, 2000). They also provide habitat for fish and wildlife populations, which contribute to hunting and fishing, bird and wildlife watching opportunities to support the local economy.

- **Habitat:** Riparian areas in natural floodplains provide terrestrial and aquatic habitat. Trees provide shade that moderates stream temperature creating conditions ideal for cool water species, such as trout. Trees also add organic material to streams, providing important habitat and nutrients to the aquatic community including fish, amphibians, reptiles and birds. Forested streams in floodplains also provide corridors for wildlife movement, creating passages for safe movement across the landscape and facilitation of genetic diversity between larger populations of mammals (Fremier et al., 2015). The greater the width of conserved natural floodplain and riparian areas, the greater the habitat value they can provide.

- **Drought mitigation:** Forested riparian areas and floodplains create shaded areas where soil moisture can be maintained in drought conditions. Additionally, tree and shrub roots hold soil in place during drought events and prevent wind erosion and soil loss. Roots prevent water from running off immediately after storms and allow it to infiltrate and recharge groundwater. Healthy riparian forests can help maintain stream flow during droughts.

- **Extreme heat mitigation:** Forested riparian areas provide heat reduction to the stream channel and other bodies of water. Vegetated natural areas can mitigate extreme heat and the urban heat island effect by providing shade and/or through the cooling effect of evapotranspiration, which releases water vapor (and thus heat energy) to the atmosphere.

- **Community, culture and recreation:** Communities value floodplains for aesthetic value and access to fishing, swimming, paddling, boating, hunting and bird and wildlife watching. Scenic qualities of streams and rivers are enhanced by stream and lakeshore vegetation.

- **Water filtration/quality:** A well-vegetated riparian area within a floodplain slows overland runoff and can filter sediments. It can also capture or convert pathogens and toxins from upland sources.

- **Sequester carbon dioxide:** Vegetated floodplains sequester carbon dioxide in both standing plants and soils. Aquatic and terrestrial plants, algae in floodplains and riparian areas store carbon and nitrogen by converting carbon dioxide and nitrogen into biomass (Palmer et al., 2009; Rheinhardt et al, 2012).

Possible effects of changes in climate and water levels on floodplains

Sea-level rise/water-level change and stronger storms

- Sea-level rise and stronger storms will increase the inland extent of floodplains. Undeveloped floodplains can adapt to this change if fill, structures and alteration of the floodplain are restricted. Adequate allow for streams to move laterally in the streamway and natural coastal features like tidal wetlands and beaches to continue to reduce risk as they migrate inland as sea-level rise.

Restored or nature-based floodplain

Restored Natural Floodplain: Floodplain restoration aims to reestablish hydrologic conditions in the floodplain. Restoration in a floodplain can include removal of manmade flood protection structures such as berms, levees or dikes, removal of fill or reduction of impervious surfaces including structures and pavement (Figure 3). It can also include revegetation and restoration in bank, wetland and riparian areas.

Nature-based Floodplain: A nature-based floodplain may consist of creating compensatory flood storage areas and the use of constructed stormwater green infrastructure techniques to capture and slowly release stormwater and floodwater. This may also be combined with nature-based coastal or stream techniques.

Credit: Delaware County Soil and Water Conservation District.

Figure A.6-4. Soil and fill were excavated and removed to restore this floodplain in Walton, NY. After vegetation becomes established the fence will be removed to reconnect the river with its floodplain. Photos show before and after excavation and regrading.

Examples of locations where restored or nature-based floodplains have been implemented

- Orange County, NY: The Nature Conservancy restored floodplain forests in the Neversink Preserve. *http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/newyork/fresh-water/neversink-floodplain-forest-restoration-slideshow.xml*
- Kings County, Washington: A levee was removed and the Upper Carlson River was reconnected to its floodplain. Invasive species were removed and 50 acres of forested floodplain was restored. *http://www.kingcounty.gov/services/environment/animals-and-plants/restoration-projects/upper-carlson-floodplain-restoration.aspx*

- ❖ Village of Walton, NY: Previously filled land was acquired along the stream and a building and fill were removed as part of the restoration of a portion of the historic floodplain area within the village to increase flood storage and mitigate flooding on nearby properties. *http://villageofwalton.com/walton/mitigation/westbrook.pdf* *http://www.dcswcd.org/Third_Brook_Plan_Frame.htm*

Factors to consider in design, construction and maintenance for restoration (if a natural feature) or construction (if a nature-based feature)

- ❖ The overall goal of floodplain restoration or creating nature-based floodplains is to reestablish hydrologic conditions. Floodplain restoration and construction should first consider removal of structures and fill that obstruct, control or modify the flow of flood waters within the floodplain. (See alternatives identified in Figure .)
- ❖ If areas are excavated to increase floodplain storage capacity, existing adjacent, undeveloped and stable (i.e. not eroding) stream and coastal reaches should be evaluated to determine appropriate size and dimensions. Hydrodynamic and hydraulic modeling tools are important tools to evaluate appropriate dimensions. Soil restoration to achieve original properties may be necessary to enhance floodplain and wetland storage and infiltration capacity.
- ❖ Ideally, a vegetated riparian buffer appropriate to the local flood regime should be established and maintained between the waterbody and other floodplain uses. Restoration of native vegetative communities augments floodplain functions.
- ❖ Use native plants to the greatest extent possible from local seed sources when available. Do not use invasive species to re-vegetate a floodplain or riparian area.

Resources

- ❖ See NYS Stormwater Management Design Manual (2015) for more guidance. *http://www.dec.ny.gov/docs/water_pdf/swdm2015entire.pdf*
- ❖ Consult with the appropriate regulatory agencies before beginning any project in or near a floodplain.

Sources

1. Association of State Floodplain Managers. (2008). Natural and Beneficial Floodplain Functions: Floodplain Management – More than Flood Loss Reduction. Retrieved from *www.floods.org*

2. Chemung County Soil & Water Conservation District (SWCD). (2006). Stream Processes: A Guide to Living in Harmony with Streams. Retrieved from *http://www.catskillstreams.org/pdfs/chemungstreamguide.pdf*

3. Ehrhart, B. (2003). Riparian Areas. Functions and Strategies for Management. Washington, D.C., USA: National Academy Press, 2002. Environmental Conservation, 30(4): 408–409

4. Federal Emergency Management Agency (FEMA). (2000). CFR 44 Section 59.1 National Flood Insurance Program (NFIP) Regulations Definitions of NFIP Terms.

5. Fischer, R. A., & Fischenich, J. C. (2000). Design Recommendations for Riparian Corridors and Vegetated Buffer Strips (No. ERDC-TN-EMRRP-SR-24). Vicksburg, MS: Army Engineer Waterways Experiment Station, Engineer Research and Development Center.

6. Fremier, A. K., Kiparsky, M., Gmur, S., Aycrigg, J., Craig, R. K., Svancara, L. K., Goble, D., Cosens, B., Davis, F., & Scott, J. M. (2015). A Riparian Conservation Network for Ecological Resilience. Biological Conservation, 191: 29–37.

7. Hollis, G. E. (1975). The Effect of Urbanization on Floods of Different Recurrence Interval. Water Resources Research, 11(3): 431–435. Retrieved from doi: *10.1029/WR011i003p00431.10.1029/WR011i003p00431*

8. Hoorman, J., & McCutcheon, J. (2005). Understanding the Benefits of Healthy Riparian Area. The Ohio State University Extension Fact Sheet LS-1-05.

9. Kline, M. (2008). A Guide to River Corridor Easements. Vermont Agency of Natural Resources River Management Program, Vermont Department of Environmental Conservation. Retrieved from *http://www.watershedmanagement.vt.gov/rivers/docs/rv_RiverCorridorEasementGuide.pdf*

10. Kline, M., & Cahoon, B. (2010). Protecting River Corridors in Vermont. Journal of the American Water Resources Association (JAWRA). 1-10. doi: 10.1111 ⁄ j.1752-688.2010.00417.x

11. New York State Department of Environmental Conservation (NYS DEC). (2015). New York State Stormwater Management Design Manual. Retrieved from *http://www.dec.ny.gov/docs/water_pdf/swdm2015entire.pdf*

12. Palmer, M. A., Lettenmaier, D.P., Poff, N. L., Postel, S., Richter, B., & Warner, R. (2009). Climate Change and River Ecosystems: Protection and Adaptation Options. Environmental Management, 44: 1053–1068.

13. Rheinhardt, R. D., Brinson, M., Meyer, G., & Miller, K. (2012). Carbon Storage of Headwater Riparian Zones in an Agricultural Landscape. Carbon Balance and Management, 7: 4. doi: 10.1186/1750-0680-7-4

A.7 – Forests

What is a forest?

A forest is an ecosystem characterized by at least 10 percent tree canopy cover, at least 1 acre in size and 120 feet in width, which is not primarily under agricultural or other specific non-forest land use (U.S. Forest Service, 2012). However, smaller areas of tree cover may provide similar benefits.

Organic matter, such as leaf litter, is essential to maintain the fertility of forest soils. Forest nutrient cycling is regulated by organisms in soils and surface litter that decompose organic matter into nutrients that are then taken up by trees and other vegetation. This process can be affected by temperature, water availability, topography, geology, soil type and carbon content, plant material, tree species composition, tree stand age and land use history. Soil nutrients can be depleted when vegetation is removed from a site for an extended time period (de la Cretaz and Barten, 2007). The growth of tree seedlings into mature trees is necessary to replace trees that are lost to disease, logging and weather events.

How do forests reduce risk?

Forests are typically part of a larger natural system which may include tidal or non-tidal wetlands, riparian areas, floodplains and streams. Conserving this larger natural system reduces risk in forests. Risk reduction will vary based on the management of individual natural features. Other measures may be needed to further reduce risk from large surge or flood events.

Forests provide the following risk reduction benefits:

- **Reduce water velocity:** A forested shore zone and riparian area can absorb the energy from waves and currents and keep ice and floating debris from encroaching on the shoreline, thereby protecting these vulnerable areas and structures from erosion and damage (Strayer and Tumblety; 2015). The above-ground vegetation in floodplain and riparian forests increases roughness or friction along the stream channel or floodway, which can reduce flow velocity (FAO, 2005; Gregory et al., 2003b; Gregory et al., 2003a).
- **Absorb water:** Forests reduce erosion on slopes by infiltrating or absorbing stormwater and promoting stormwater infiltration and reducing surface runoff (FAO, 2005; Gregory et al., 2003a) (Figure A.7-1 and Figure A.7-2). The combined presence of leaf litter, a thick organic layer, complex pore structures and deep root systems in forest soils all promote stormwater infiltration. This minimizes surface runoff and may reduce local flood risk by smoothing out fluctuations in stream flow and lowering flood height (de la Cretaz and Barten 2007; Gartner et al., 2014; Gregory et al., 2003a). Flood risk-reducing benefits are most evident for short duration and low-intensity rainfall events before the ground becomes saturated. Once soil saturation is reached surface runoff will occur,

limiting the ability of forests to prevent local or downstream flooding (Bruijnzeel, 2004; FAO, 2005). Forest water storage capacity also depends on soil type, soil depth and past land use. In general, forests provide increased water storage capacity compared to urban or impervious land cover.

- **Stabilize sediment:** The deep, sturdy root structures of trees and shrubs stabilize shorelines and can effectively buffer impacts from current, wave or wake energy. When surface runoff does occur in forests, leaf litter and understory vegetation help to slow the overland flow and protect soils from erosion (FAO, 2005; Gregory et al., 2003a).

Credit: NYS DEC.

Figure A.7-1. Headwater forests where streams begin are especially important to reducing downstream flood impacts.

Credit: NYS DEC.

Figure A.7-2. Large forests help to capture and absorb rainfall, minimizing runoff and erosion.

Forces and conditions that forests can mitigate to reduce risks to people and communities

- Currents generally parallel to the shoreline causing damage from erosion, floating debris or the mobilization of ice
- Waves, wakes and surges generally perpendicular to the shoreline causing damage from erosion, floating debris or the mobilization of ice
- Precipitation or meltwater moving downhill to nearest waterbody causing erosion, temporary pooling and localized property damage
- Temporarily elevated water levels from surge, high river flows or high lake levels inland of the shoreline causing property damage

Human activities that reduce or impair risk-reduction capacity

- Timber harvesting can result in temporary increases in runoff and water infiltration rates leading to higher stream flows (Gregory et al., 2003a,b), but this effect quickly diminishes in healthy forests as vegetation regenerates. Tree death from forest pests and diseases may have similar temporary effects until new vegetation is established. Soil movement and compaction during timber harvest operations (e.g., road construction, skidding, etc.) are more long-lasting impacts that increase runoff and result in erosion, but can be minimized through the use of best management practices (NYS DEC, 2011).

- Forest clearing for new development and paved roads will increase stormwater runoff and impair the risk reduction benefits of forests (de la Cretaz and Barten, 2007).
- Human introduction of invasive pests and diseases presents threats to forest diversity and/or potential deforestation of species-specific habitats. Examples include Emerald ash borer (*Agrilus planipennis*), Asian Long-horned beetle (*Anoplophora glabripennis*), Hemlock woolly adelgid (*Adelges tsugae*) and Oak wilt (*Ceratocystis fagacearum*, a fungus).
- Forest understory vegetation and leaf litter are largely responsible for controlling erosion and sediment processes in forests by protecting forest soils from the direct impact of rainfall and runoff and slowing the flow of runoff where it occurs. Clearing, excessive deer browse, invasive earthworms reduce leaf litter and organic matter on the forest floor and reduce the stormwater-related benefits of forests (FAO, 2005; Gartner et al., 2014).
- Actions such as filling or ditching can reduce a forest's ability to intercept and absorb runoff.
- Development and new roads increase the potential for the invasion of exotic species that will out compete native ones. Loss of habitat for predators like coyotes results in higher deer populations. Over-browsing by deer can prevent survival of saplings and the regeneration and establishment of mature forest trees (New York Natural Heritage Program, 2017).

Other benefits

Forests provide a range of other benefits, including the following:

- **Economic:** The forest products industry in New York State including timber harvesting and conversion into lumber, veneer, pulp, paper, energy or secondary manufactured wood products contributed over $9.9 billion dollars to the economy in 2012 (Figure A.7-3). In addition, forest-based recreation and tourism generated sales of $8.2 billion resulting from a wide range of activities including fall foliage viewing, hiking, camping, hunting, skiing and wildlife observation (NEFA 2013).
- **Habitat:** Although forests of all sizes have some habitat value, large contiguous forests that are unbroken by major roads or other development are especially important for a number of species sensitive to disturbance and dependent on large areas to meet their habitat requirements, including several large mammals (e.g., bobcat, black bear, fisher), raptors (e.g. red-shouldered hawk, Cooper's hawk), songbirds (e.g., woodland warblers, forest thrushes) and woodland salamanders, among other species. Smaller forests are particularly important where they serve as corridors or stepping stones between large intact forest blocks, facilitating species movement (Penhollow et al., 2006).

- **Drought mitigation:** Forests promote groundwater recharge and help maintain healthy streamflow, which can mitigate drought. However, trees are heavy water users and can reduce overall water yield which may exacerbate drought effects (FAO 2005; Gartner et al. 2014). Tree and shrub roots hold soil in place during drought events and minimize wind erosion and soil loss.

- **Extreme heat mitigation:** Vegetated natural areas can mitigate extreme heat and the urban heat island effect by providing shade and/or through the cooling effect of evapotranspiration, which releases water vapor (and thus heat energy) to the atmosphere. The cooling effect of forests in riparian areas is also critical to maintaining low stream water temperatures required by many aquatic organisms.

- **Community, culture and recreation:** Communities value forests for scenery and providing access for hiking, hunting, trapping and bird watching. They can be closely coupled with some communities' sense of place and local cultural traditions.

- **Water filtration/quality:** Perhaps the most significant contribution of forests to watershed ecosystems is in maintaining high water quality. Forests stabilize slopes and minimize on-site erosion, reduce sediment entering water bodies and trap, filter, absorb or convert excess nutrients and other water pollutants as runoff passes through the forest litter layer and infiltrates the soil. Trees exposed to high levels of air pollution in urban or mountainous areas can capture sulphur and nitrogen, reducing water acidification. (Calder et al., 2007)

- **Carbon sequestration:** Trees and other forest vegetation sequester carbon. Some forest owners in New York are taking advantage of new carbon markets based on forest carbon sequestration potential (NEFA 2013). In 2017, the average price in the global market for sequestered carbon was $9.50/metric ton for improved forest management practices (Hamrick, K. and M. Gallant, 2017). A typical New York forest holding can be between 15-50 marketable metric tons per acre and after all expenses, landowner shares can result in payments upwards of $250/acre (Troy Weldy, personal communication, April 27, 2018).

Credit: K. Strong.

Figure A.7-3. Forestry that follows best management practices is compatible with maintaining flood-risk benefits of forests.

Possible effects of changes in climate and water levels on forests

Stronger storms

- Forested slopes may nevertheless be vulnerable to erosion and landslides as a result of extreme rainfall events, as witnessed in the Catskills in the aftermath of Hurricane Irene and Tropical Storm Lee.
- Increased weather-related disturbances may also favor the spread of invasive species and distort insect, disease and fire dynamics, reducing forest health and natural benefits. Forested shorelines may be vulnerable to extreme events, with steep slopes more vulnerable than gradual inclines.

Warmer temperatures and short-term drought

- Tree species are sensitive to changes in temperature and precipitation and the distribution of common species in New York is expected to shift with climate change (Rosenzweig et al., 2011). It is likely to alter natural disturbance regimes, favoring the spread of invasive species, distorting insect and disease dynamics and shifting species and community ranges (Gunn et al., 2009). Certain species will shift distribution farther north and upslope in response to inhospitable conditions, while others may experience dieback. This process will result in changes to forest species composition over time, as trees intolerant to rising temperatures or changing precipitation patterns succumb to stress and are replaced by species adapted to the changing conditions in the forest. One study indicated that oak forests will have the opportunity to dominate many areas of New York presently occupied by maple and other valuable hardwood species (Iverson et al., 2008). Nevertheless, trees are long-lived and questions remain about the rate at which actual changes will occur. It is uncertain how this process will affect the climate risk-reducing benefits of forests. Forest management may be necessary to maintain the many ecosystem services provided by forests under these rapidly changing conditions.

- Forest regeneration is the growth of tree seedlings into mature trees, and is an important measure of forest health. A recent Nature Conservancy study indicates that 32% of New York State's forests may not have sufficient regeneration to replace the forest canopy after a significant disturbance event, like a strong storm, with the poorest regeneration conditions in the southeast portion of the state, including Long Island, the southern Hudson Valley and southern Catskills (Shirer and Zimmerman, 2010). Deer browse is a primary factor limiting forest regeneration in New York; however, invasive plants, lack of scientific forest management, changing weather patterns, air pollution and forest pests and diseases may all contribute to inadequate regeneration.

Restored or nature-based forest

Restored Natural Forests: Forest restoration could include fencing to protect natural forests from deer over-browsing; removal of invasive species and the planting of native forest seedlings to promote natural succession; and transplanting native seedlings to degraded sites.

Nature-based Forests: A nature-based approach might include the above plus approaches to stabilize an eroding streambank or manage runoff using nature-based stream or constructed stormwater green infrastructure techniques.

Examples of locations where restored or nature-based forests have been implemented

- New York State was largely forested prior to European settlement. By the 1880s, less than 20 percent of New York was forested. The 1885 Forest Preserve Act, the 1929 State Reforestation Act and the 1931 Hewitt Amendment authorized the State Conservation Department to conserve and buy land for reforestation purposes and create the State Forest System. Many marginal agricultural lands across the state left fallow by the late 19th and early 20th century and naturally reverted to forest.
- Today, New York's approximately 30 million acres of forest are mainly of natural origin, with fewer than 1 million acres of plantations. Plantation forestry has waned substantially in recent decades, and some older plantations are being converted back to a natural forest condition. Current day restoration projects are primarily urban and community forestry and stream riparian buffer restoration projects, such as New York

City's Million TreesNYC campaign and the DEC Trees for Tribs initiative (Verschoor and Van Duyne, 2012) (*www.dec.ny.gov/animals/77710.html)*.

- DEC's "Trees for Tribs" Program: This program is actively replanting riparian buffers in targeted high risk areas (*www.dec.ny.gov/animals/77710.html)*.
- Mine reclamation projects are opportunities to restore native forests. The Thalle Industries Quarry in Fishkill, NY planted trees and shrubs along terraces to restore native oak hickory forest as part of a mine reclamation project (Figure A.7-4).

Credit: NYS DEC.

Figure A.7-4. Forest restoration along terraces in the Thalle Industries Quarry in Fishkill, NY.

Factors to consider in design, construction and maintenance for restoration (if a natural feature) or construction (if a nature-based feature)

- If the soils are dense and compacted they may need to be amended with topsoil.
- Take care to ensure that existing vegetation or new invasive species don't out-compete seedlings.
- Select native tree species that will grow well in local conditions and be viable as the climate changes.
- Ensure seedlings and natural forest regeneration is protected from excessive deer browse.

Resources

- The Center for Watershed Protection, in cooperation with the USDA Forest Service Northeastern Area State and Private Forestry published the *Urban Watershed Forestry Manual* (2005) with guidance for planting trees in a variety of settings. www.na.fs.fed.us/watershed/publications.shtm
- New York City Department of Parks and Recreation has also published Guidelines for Urban Forest Restoration (2014). www.nycgovparks.org/greening/natural-resources-group/publication.
- Consider buying New York-grown seedlings. The New York State Tree Nursery in Saratoga Springs provides low-cost trees and shrubs to landowners, produced from local seed sources and adapted to local conditions during the annual spring seedling sale. www.dec.ny.gov/animals/7127.html
- The Nature Conservancy's online Natural Resource Navigator tool synthesizes spatial data on forest conditions, threats, climate change exposure and sensitivity and recommends adaptation strategies. It includes a library of resources related to forest adaptation management. www.naturalresourcenavigator.org
- *Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers* (Swanston and Janowiak, 2012). provides a collection of resources designed to help forest managers incorporate climate change considerations into management and adaptation. www.nrs.fs.fed.us/pubs/40543
- The Chesapeake Bay Program in cooperation with the USDA Forest Service developed the *Chesapeake Bay Riparian Handbook: A guide for establishing and maintaining riparian forest buffers,* which provides guidance on the design, restoration and management of riparian forests. This document also discusses the function and importance of riparian forests for water quality and flood control http://www.chesapeakebay.net/content/publications/cbp_13019.pdf
- NYS has several forestry-related programs (NYS DEC, 2011):
  - The NYS DEC Forest Stewardship Program can provide non-industrial forest landowners with no cost one-on-one technical assistance that includes creating a stewardship plan tailored to individual goals and objectives.
  - The NYS DEC Cooperating Forester program encourages landowners to work with private foresters in managing their woodlots.
  - New York State's 480-a forest tax law provides up to an 80% reduction in local property taxes in return for continued forest management of enrolled landowners with at least 50 acres of forest to encourage the long-term management of forest land.
  - Other information about NYS DEC's private forest management programs at www.dec.ny.gov/lands/4972.html and BMP guidance at www.dec.ny.gov/docs/lands_forests_pdf/dlfbmpguide.pdf.

- NYS DEC's Trees for Tribs staff may be able to provide site specific guidance for forest restoration in riparian areas. http://www.dec.ny.gov/animals/77710.html

Sources

1. Bruijnzeel, L. A. (2004). Hydrological Functions of Tropical Forests: Not Seeing the Soil for the Trees? Agriculture Ecosystems and Environment, 104(1): 185–228.

2. Calder, I., Hofer, T., Vermont, S., & Warren, P. (2007). Towards a New Understanding of Forests and Water. Unasylva, 229: 3–10.

3. Center for Watershed Protection. (2005). Urban Watershed Forestry Manual: Parts 1–3. Newtown Square, PA: U.S. Department of Agriculture Forest Service Northeastern Area State and Private Forestry. Retrieved from http://www.na.fs.fed.us/watershed/publications.shtm

4. de la Cretaz, A. L., & Barten, P. K. (2007). Land Use Effects on Streamflow and Water Quality in the Northeastern United States. Boca Raton, FL: CRC Press.

5. Food and Agriculture Organization of the United Nations (FAO). (2005). Forests and Floods: Drowning in Fiction or Thriving on Facts? RAP Publication 2005/03. Rome: FAO and Center for International Forestry Research. Retrieved from http://www.fao.org/docrep/008/ae929e/ae929e00.htm

6. Fremier, A. K., Kiparsky, M., Gmur, S., Aycrigg, J., Craig, R. K., Svancara, L. K., Goble, D., Cosens, B., Davis, F., & J.M. Scott. (2015). A Riparian Conservation Network for Ecological Resilience. Biological Conservation, 191: 29–37.

7. Gartner, T., McGray, H., Mulligan, J., Epstein, J., & Dinshaw, A. (2014). Adaptation: Forests as Water Infrastructure in a Changing Climate. In Forest Conservation and Management in the Anthropocene: Conference Proceedings. Proceedings RMRS-P-71 (pp. 313-337). Fort Collins, CO: U.S. Department of Agriculture, Forest Service. Rocky Mountain Research Station. Retrieved from http://www.fs.fed.us/rm/pubs/rmrs_p071.html

8. Gregory, S., Nisbet, T., & McKay, H. (2003a). Forests and Water. Sustainable Forestry in Brief. UK Forestry Commission. Retrieved from http://www3.hants.gov.uk/forestsandwater.pdf

9. Gregory, S., Nisbet, T., & McKay, H. (2003b). Forests and Flooding. Sustainable Forestry in Brief. UK Forestry Commission. Retrieved from http://www3.hants.gov.uk/forestsandflooding.pdf

10. Gunn, J. S., Hagan, J. M., & Whitman, A. A. (2009). Forestry Adaptation and Mitigation in a Changing Climate: A Forest Resource Manager's Guide for the Northeastern United

States. Report NCI-2009-1. Brunswick, ME: Manomet Center for Conservation Sciences. Retrieved from *www.manometmaine.org*

11. Hamrick, K., & Gallant, M. (2017). Unlocking Potential: State of the Voluntary Carbon Markets 2017 (p.11). Retrieved from *https://www.cbd.int/financial/2017docs/carbonmarket2017.pdf*

12. Iverson, L. R, Prasad, A. M., Matthews, S. N., & Peters, M. (2008). Estimating Potential Habitat for 134 Eastern US Tree Species under Six Climate Scenarios. Forest Ecology and Management, 254: 390–406. Retrieved from *http://www.nrs.fs.fed.us/pubs/jrnl/2008/nrs_2008_iverson_002.pdf*

13. New York City Department of Parks and Recreation. (2014). Guidelines for Urban Forest Restoration. New York, NY: New York City Department of Parks and Recreation. Retrieved from *www.nycgovparks.org/greening/natural-resources-group/publication*

14. New York State Department of Environmental Conservation (NYS DEC). (2011). New York State Forestry Best Management Practices for Water Quality: BMP Field Guide. (2011 edition). Albany, NY: NYS DEC. Retrieved from *http://www.dec.ny.gov/docs/lands_forests_pdf/dlfbmpguide.pdf*

15. North East State Foresters Association (NEFA). (2013). The Economic Importance of New York's Forest-Based Economy, 2013. Retrieved from *http://www.nefainfo.org/uploads/2/7/4/5/27453461/nefaeconomicimportny.pdf*

16. Penhollow, M., Jensen, P., & Zucker, L. (2006). Wildlife and Habitat Conservation Framework: An Approach for Conserving Biodiversity in the Hudson River Estuary Corridor. Ithaca, NY: New York Cooperative Fish and Wildlife Research Unit, Cornell University and New York State Department of Environmental Conservation, Hudson River Estuary Program. Retrieved from *http://www.dec.ny.gov/lands/5096.html*

17. Rosenzweig, C., Solecki, W., DeGaetano, A., O'Grady, M., Hassol, S., & Grabhorn, P. (Eds.). (2011). Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation. NYSERDA Report 11-18. Albany, NY: New York State Energy Research and Development Authority. Retrieved from *www.nyserda.ny.gov/climaid*

18. Shirer, R., & Zimmerman. C. (2010). Forest Regeneration in New York State. Albany, NY: The Nature Conservancy. Retrieved from *http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/newyork/lands-forests/final-nys-regen-091410-2.pdf*

19. Strayer, D., & Tumblety, L. (2015). Managing Shore Zones for Ecological Benefits: Handbook. Staatsburg, NY: Hudson River Sustainable Shorelines Project, Hudson River National Estuarine Research Reserve. Retrieved from *https://www.hrnerr.org/doc/?doc=273743856*

20. Swanston, C., & Janowiak, M. (Eds.). (2012). Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers. Gen. Tech. Rep. NRS-87. Newtown Square, PA: U.S. Forest Service Northern Research Station. Retrieved from *http://www.nrs.fs.fed.us/pubs/40543*

21. U.S. Forest Service. (2012). Forest Inventory and Analysis National Core Field Guide: Volume I: Field Data Collection Procedures for P2 Plots (Ver. 6.0). Washington, D.C.: U.S. Department of Agriculture, Forest Service. Retrieved from *http://www.fia.fs.fed.us/library/field-guides-methods-proc/docs/2013/Core%20FIA%20P2%20field%20guide_6-0_6_27_2013.pdf*

22. Verschoor, K., & Van Duyne, G. (2012). Forestry and Tree Planting in New York State. Tree Planter's Notes, 55(2): 4–13. Retrieved from *http://www.rngr.net/publications/tpn/55-2/forestry-and-tree-planting-in-new-york-state*

A.8 – Inlet

What is an inlet?

Inlets are natural channels or waterways that either periodically or continuously contain moving water, and form a connecting link between two bodies of water (Figure A.8-1 and Figure A.8-2). Adjacent waterbodies are the primary source of water passing through inlets. Breaches are a type of naturally occurring inlet. They typically form when storm waves or surge cut through coastal barrier islands or spits. A breach can also form if the water pressure in an enclosed waterbody is sufficient to break through a land barrier. Other examples of inlets include narrow waterways connecting bays, lagoons or lakes; tidal openings in barrier islands and river or tributary entrances to bays or lakes or oceans. (Adapted from USACE, 2003). Inlets reduce risk by reducing water velocity, supplying sediment to other natural features and conveying or draining water.

In general, stable inlets represent a balance between the movement of sediment drifting into the inlet, through longshore sediment transport, and the scouring capability of the currents generated at the inlet (Byrne et al., 1974). However, inlets are likely to move or change significantly as energy and water from strong storms and other sources are absorbed. These changes are often difficult to predict. *For this reason, structures or assets sited near inlets are considered to be at greater risk.* With sufficient longshore sediment supply breach inlets gradually elongate in the direction of net sediment transport. The historic record in New York indicates breaches may close over time with natural sediment transport.

Tidal inlets may also function as sediment reservoirs, storing and releasing sediment within a regional system (Barnhardt, 2009). Ebb and flood tidal deltas form at the mouths of inlets based on sediment distribution and flow rates from the contributing basins through the inlet system.

Credit: Carolyn Fraioli.

Figure A.8-1. A coastal inlet influenced by tides.
Dotted lines indicate where shoals form in the ebb and flood tidal deltas. An arrow indicates the direction of longshore sediment transport, also known as littoral drift, which moves sediment along the shoreline.

Credit: National Park Service.

Figure A.8-2. Aerial view of a new inlet on a barrier island at Fire Island National Seashore, as seen from the Atlantic Ocean to the bay.

How do inlets reduce risk?

Inlets are typically part of a larger natural system which may include barrier islands, beaches, nearshore areas and shoals. Conserving and maintaining this larger natural system reduces risk near inlets. Risk reduction will vary based on the management of individual natural features. Other measures may be needed to further reduce risks from large surge or flood events.

Inlets provide the following risk reduction benefits:

- **Reduce water velocity:** Natural inlets and their connecting floodplains provide areas for water to slow down and spread out. Shallow inlets allow for water conveyance, but can still provide friction to attenuate surge (Orton et al., 2015).
- **Supply sediment:** Inlets deliver sediment into connecting waterbodies, creating deltas and providing sediment for nearshore areas, beaches and wetlands that provide habitat and reduce risk of erosion. Natural coastal inlets typically move sand across delta sandbars or shoals, allowing sand to supply downdrift beach areas.
- **Provide conveyance/draining:** Although inlets admit storm surges into bays and lagoons, thus contributing to temporary elevated water levels and flooding, they also serve to drain off surge waters during a storm event or rainfall event, reducing the possibility of new inlet breaching (Leatherman, 1989) and reducing bay-shore flooding.

The number and size of inlets present in a barrier island system may affect back bay water levels.

Forces and conditions that inlets can mitigate to reduce risks to people and communities

- Currents generally parallel to the shoreline causing damage from erosion, floating debris or the mobilization of ice
- Waves, wakes and surges generally perpendicular to the shoreline causing damage from erosion, floating debris or the mobilization of ice
- Temporarily elevated water levels from surge, high river flows or high lake levels inland of the shoreline causing localized property damage

Human activities that reduce or impair risk-reduction capacity

- Dredging to make wider and deeper inlets can reduce friction, leading to higher water volume and energy entering bays. Maintenance dredging of navigation channels through inlets (e.g. Great South Bay on Long Island), while necessary, can also create a sediment sink which intercepts sediment moving along the shore and may accelerate erosion of downdrift beaches. However, proper disposal of dredge sediments back into the shore zone downdrift of the inlet can offset this effect.
- The traditionally straight and uniform design of maintained navigation channels can accelerate the velocity of tidal flow or surges, causing an increased risk.
- Physical barriers to sediment transport (such as groins, jetties or breakwaters) can interrupt the natural sediment transport processes that build up shoals or offshore sandbars associated with inlets, reducing their ability to mitigate incoming wave energy.
- The movement, adjustment or creation of an inlet where it has not historically existed, in order to protect development or navigation, often requires a lot of expensive maintenance and can include physical stabilization structures. Stabilized inlets often act as a sediment sink, accelerating erosion of downdrift beaches.

Other benefits

Inlets provide a range of other benefits, including the following:

- **Economic:** Inlets are very valuable for navigation and are also popular for recreational fishing. In some cases, they can be harnessed for hydro-power.
- **Habitat:** Inlets can improve water quality by increasing water circulation and flushing. They can also improve habitat connectivity. They are essential for the movement of migratory fish species. Inlets formed by breaches can also provide sand and sediments to the bay side, which encourages wetland migration.

- **Community, culture and recreation:** Communities value inlets for marine mammal charters and for recreational boating and fishing. Fishing and shellfishing are dependent on good water quality, which depends on good water circulation. Recreational boat marinas are frequently connected to navigable waterbodies through inlets.
- **Water filtration/quality:** Inlets improve water exchange between waterbodies (e.g., bay and ocean), improving water circulation and water quality.

Possible effects of changes in climate and water levels on inlets

Sea-level rise/water-level change

- Rising water levels will widen and deepen inlets.

Stronger storms

- Potential changes in storm intensity could change sediment transport patterns and lead to the opening or closing of inlets and breaches on coastal barrier islands and in large lake and estuarine systems. Maintenance will likely be required over time to manage channels and inlets that are critical for navigation or to manage flood risks.

Restored or nature-based inlet

Restored Inlets: Inlets can be restored through reconstruction, shallowing, texturing (i.e., increasing the roughness of the bottom) or balancing sediment deposits and flow rates, all of which contribute to risk reduction.

Note: NYS does not consider the use of structural components to stabilize or maintain inlets a nature-based feature because it will largely disrupt natural long- and cross-shore sediment transport and water access to the floodplain. Inlets that are artificially created, diverted, stabilized, confined or maintained by dredging may increase flood and erosion risks and/or provide limited risk reduction benefits and ecological value.

Examples of locations where restored or nature-based inlets have been implemented

- Fire Island Otis Peak High Dune Wilderness Area: A breach in Fire Island National Seashore, owned by the National Park Service, formed an inlet that has been left open to study its evolution over time (USGS, 2016; Great South Bay, n.d.; NPS, n.d.).
- Work by P. Orton et al. (2015) on Jamaica Bay/Rockaway Inlet restoration and work by Kraus et al. (2003) on hypothetical relocation of Fire Island inlet indicate that channel or inlet shallowing could have an effect on risk.

Factors to consider in design, construction and maintenance for restoration (if a natural feature) or construction (if a nature-based feature)

Recommendations:

- Activities in the areas of dredging and dredged material placement, including regulatory actions, come under the jurisdiction of the National Environmental Policy Act (NEPA). The USACE has developed guidance on dredging and material placement. (USACE, 2015)
- Inlets are very dynamic and their stability may be unpredictable. Reducing development pressure and allowing sufficient room for them to migrate over time and provide natural sediment transport and supply functions may be preferable to construction or significant restoration in many situations.
- Modeling of how water and sediment will move at particular sites can help to predict whether a channel or inlet will remain stable naturally or need maintenance over time. An ongoing study of the Fire Island Wilderness breach utilizes both monitoring observations and modeling to assess future breach stability (USGS, 2016).
- Consult with the appropriate regulatory agencies before beginning any project near an inlet.

Sources

1. Barnhardt, W. A. (2009). Coastal Change Along the Shore of Northeastern South Carolina: The South Carolina Coastal Erosion Study. Retrieved from *http:/pubs.usgs.gov/circ/circ1339/*

2. Byrne, R. J., DeAlteris, J. T., & Bullock, P. A. (1974). Channel Stability in Tidal Inlets: A Case Study. Coastal Engineering Proceedings, 1(14).

3. FitzGerald, D. M. (1988). Shoreline Erosional-Depositional Processes Associated with Tidal Inlets. In: Hydrodynamics and Sediment Dynamics of Tidal Inlets (pp. 186–225). Springer New York.

4. FitzGerald, D. M., Kraus, N. C., & Hands, E. B. (2000). Natural Mechanisms of Sediment Bypassing at Tidal Inlets (No. ERDC/CHL-CHETN-IV-30). Vicksburg, MS: Engineer Research and Development Center, Coastal and Hydraulics Lab.

5. Goudie, A. S. (Ed.) (2004). Encyclopedia of Geomorphology (Vol. 2). Psychology Press.

6. Great South Bay. (n.d.). The Great South Bay Project. Retrieved from *http://po.msrc.sunysb.edu/GSB/*

7. Kraus, N. C., Zarillo, G. A., & Tavolaro, J.F. (2003). Hypothetical Relocation of Fire Island Inlet, New York. In: Proceedings Coastal Sediments '03. CD-ROM. Corpus Christi, TX: World Scientific and East Meets West.

8. Leatherman, S. (1989). Role of Inlets in Geomorphic Evolution of the South Shore Barriers of Long Island, New York, USA. Environmental Management, 13(1): 109–115.

9. National Park Service (NPS). (n.d.), Document List: Fire Island National Seashore Breach Management Plan/EIS. Retrieved from *https://parkplanning.nps.gov/documentsList.cfm?parkID=227&projectID=58824*

10. Orton, P., Talke, S. A., Jay, D. A., Yin, L., Blumberg, A. F., Georgas, N., Zhao, H., Roberts, H. J., & McManus, K. (2015). Channel Shallowing as Mitigation of Coastal Flooding. Journal Marine Science and Engineering 3(3): 654–673.

11. U.S. Army Corps of Engineers (USACE). (n.d.). History of MRGO. Retrieved from *http://www.mvn.usace.army.mil/Missions/Environmental/MRGO-Ecosystem-Restoration/History-of-MRGO/*

12. U.S. Army Corps of Engineers (USACE). (2003). Coastal Engineering Manual, EM 1110-2-1100, Change 2, Glossary, Appendix A (p. A-14).

13. U.S. Army Corps of Engineers (USACE). (2015). Dredging and Dredged Material Management. Engineer Manual *http://publications.usace.army.mil/publications/*

14. U.S. Geological Survey (USGS). (2016). Storm Impact and Recovery: Hurricane Sandy – Wilderness Breach. Retrieved from *https://coastal.er.usgs.gov/f,sire-island/research/sandy/sandy-breach.html*

A.9 – Maritime Forest

What is a maritime forest?

In the northeast, maritime forests occur in maritime portions of the coastal lowlands on sheltered backdunes, bluffs or more interior coastal areas not directly influenced by overwash, but affected by salt spray and wind-pruning (Figure A.9-1 and Figure A.9-2). They are rare in New York. Known examples range from Caswell Cliff on Montauk Point, west to Friars Head on the north shore of Long Island and Sunken Forest on the south shore of Long Island. Successional maritime forests can also occur on areas of abandoned farmland or where vegetation has been burned or land cleared near marine communities. Species such as black and white oak, hickory, pitch pine, black cherry, serviceberry and black gum can be found in maritime forests. Species composition will vary based on site characteristics and land history.

Maritime forests are often associated with areas that accrete behind dunes. After dunes form, grasses and shrubs colonize the back dune area and begin to stabilize sand and add nitrogen to the soil. Once soil nitrogen levels have risen, trees will begin to colonize as well (Lopazanski, 1988). Consistent wind-blown sand and stable foredune and beach systems can support a stable maritime forest.

Organic matter, such as leaf litter, is essential to maintain the fertility of forest soils. Forest nutrient cycling is regulated by organisms in soils and surface litter that decompose organic matter into nutrients that are then taken up by trees and other vegetation. This process can be affected by temperature, water availability, topography, geology, soil type and carbon content, plant material, tree species composition, tree stand age and land use history. Soil nutrients can be depleted when vegetation is removed from a site for an extended time period (de la Cretaz and Barten, 2007). The growth of tree seedlings into mature trees is necessary to replace trees that are lost to disease, logging and weather events.

Credit: © The Nature Conservancy (Kara Jackson).

Figure A.9-1. A maritime forest forming on a shallow dune at Cedar Beach County Park in Southold, NY.

Credit: © The Nature Conservancy.

Figure A.9-2. An example of a maritime forest along Bass Creek at The Nature Conservancy's Mashomack Preserve on Shelter Island in Suffolk County, NY.

How do maritime forests reduce risk?

Maritime forests are typically part of a larger coastal system which may include beaches, dunes, forests, bluffs and nearshore areas. Conserving and maintaining this larger natural system reduces risk near maritime forests. Risk reduction will vary based on the management of individual natural features. Other measures may be needed to further reduce risks from large surge or flood events.

Maritime forests provide the following risk reduction benefits:

- **Reduce water velocity:** The above-ground vegetation in floodplain forests increases roughness or friction, which can reduce flow velocity (FAO, 2005; Gregory et al., 2003b; Gregory et al., 2003a). Vegetation can physically capture and by creating friction, dissipate energy from incoming storm surge reducing height and penetration of water. Vegetation also promotes accretion that can raise land elevation over time.
- **Absorb water:** Forests reduce erosion on slopes by infiltrating and reducing surface runoff (FAO, 2005; Gregory et al., 2003a). The structure of forest soils promotes stormwater infiltration; in particular, the presence of leaf litter, a thick organic layer, complex pore structures and deep root systems. This minimizes surface runoff and may reduce local flood risk by smoothing out fluctuations in stream flow and lowering flood height (de la Cretaz and Barten 2007; Gartner et al., 2014; Gregory et al., 2003a). Flood risk-reducing benefits are most evident for short duration and low-intensity rainfall events before the ground is saturated (Bruijnzeel, 2004; FAO, 2005).
- **Stabilize sediment:** Maritime coastal forests stabilize coastal landforms like barrier islands and their root systems retain soil (Cunniff and Schwarz, 2015). The deep, sturdy root structures of trees and shrubs stabilize sediment and can effectively buffer current, wave or wake energy. When surface runoff does occur in forests, leaf litter and understory vegetation help to slow the overland flow and protect soils from erosion (FAO, 2005; Gregory et al., 2003a).

Forces and conditions that maritime forests can mitigate to reduce risks to people and communities

- Currents generally parallel to the shoreline causing damage from erosion, floating debris or the mobilization of ice
- Waves, wakes and surges generally perpendicular to the shoreline causing damage from erosion, floating debris or the mobilization of ice
- Precipitation or meltwater moving downhill to nearest waterbody causing erosion, temporary pooling and localized property damage
- Temporarily elevated water levels from surge, high river flows or high lake levels inland of the shoreline causing localized property damage

Human activities that reduce or impair risk-reduction capacity

- Thinning, cutting or removing stems reduces aboveground biomass and the proportional capacity to physically capture and dissipate energy from incoming storm surge.
- Damage to root systems by trampling or vehicles, removal of fronting dune or vegetation, excavation, groundwater inundation, fire, fragmentation, salt water intrusion can lead to loss of vegetation and de-stabilization of soils.
- Maritime forests are very susceptible to fragmentation due to development pressure, fires, invasive species (Lopazanski, 1988) and deer browse. Development and new roads increase the potential for the invasion of exotic species that will out compete native ones. Loss of habitat for predators like coyotes results in higher deer populations. Over-browsing by deer can prevent survival of saplings and the regeneration and establishment of mature forest trees (New York Natural Heritage Program, 2017).

Other benefits

Maritime forests provide a range of other benefits, including the following:

- **Economic:** Maritime forests reduce wind and salt spray and offer recreational benefits.
- **Habitat:** Maritime forests are important migratory bird habitat.
- **Drought mitigation:** Forests promote groundwater recharge which can mitigate drought effects and can help maintain healthy stream flows. However, trees are heavy water users and can reduce overall water yield which may exacerbate drought effects on water yield (FAO 2005; Gartner et al. 2014). Tree and shrub roots hold soil in place during drought events and prevent wind erosion and soil loss.
- **Extreme heat mitigation:** Vegetated natural areas can mitigate extreme heat and the urban heat island effect by providing shade and/or through the cooling effect of evapotranspiration, which releases water vapor (and thus heat energy) to the atmosphere.
- **Community, culture and recreation:** Maritime forests are unique and increasingly rare in NYS (New York Natural Heritage Program, 2017). Communities value them for scenery and providing access for boating, fishing, swimming, hiking, hunting, trapping and bird watching. Maritime forests were traditional hunting areas, now mostly birders use them (Whitaker et al., 2009). They can be closely coupled with some communities' sense of place and local cultural traditions.
- **Water filtration/quality:** Perhaps the most significant contribution of forests to watershed ecosystems is in maintaining high water quality. Forests stabilize slopes and minimize on-site erosion, reduce sediment entering water bodies and trap, filter, absorb or convert excess nutrients and other water pollutants as runoff passes through the forest litter layer and infiltrates the soil. Maritime forests add organic matter to the soil,

which improves its water holding capacity (its ability retain flood water) Forests can protect fresh water aquifers (DNREC, 2000).

- **Carbon sequestration:** The vegetation in maritime forests sequesters carbon dioxide.

Possible effects of changes in climate and water levels on maritime forests

Sea-level rise

- It is unclear if this feature will need to be actively managed with sea-level rise or if it will naturally colonize upland areas without human intervention.

Stronger storms and warmer temperatures

- Dunes that protect maritime forests may be lost in strong storms or if sediment transport processes that supply the dunes are compromised. Loss of the dunes may destabilize the forest vegetation. Dunes will need to be maintained or replaced or the forests may be lost (Lopazanski, 1988).
- Warmer temperatures could increase the ranges of invasive species, which are degrading the quality of the maritime forests still in existence. They must be adaptively managed to ensure native plant survival and propagation. (VIMS, 2017)
- Forest regeneration is the growth of tree seedlings into mature trees, and is an important measure of forest health. A recent Nature Conservancy study indicates that 32% of New York State's forests may not have sufficient regeneration to replace the forest canopy after a significant disturbance event, like a strong storm, with the poorest regeneration conditions in the southeast portion of the state, including Long Island, the southern Hudson Valley and southern Catskills (Shirer and Zimmerman, 2010). Deer browse is a primary factor limiting forest regeneration in New York; however, invasive plants, lack of scientific forest management, changing weather patterns, air pollution and forest pests and diseases may all contribute to inadequate regeneration.

Restored or nature-based maritime forest

Restored Maritime Forest: Maritime forest restoration could include fencing to protect natural forests from deer over-browsing, removal of invasive species and the planting of native maritime forest seedlings to foster successional growth. Restoration of maritime forests should include installation of groundcover, shrub layer and intermittent canopy trees.

Nature-based Maritime Forest: A nature-based maritime forest might include the planting, nurturing and management of maritime forest seedling species in combination with or as a component of a nature-based coastal technique such as a nature-based dune or beach.

Examples of locations where restored or nature-based maritime forests have been implemented

- Cape May, NJ: Invasive plants are being removed to restore a maritime forest in Cape May with the help of volunteers *http://www.njaudubon.org/SectionConservation/StewardshipProgam/StewardshipBlog/tabid/2006/entryid/72/Volunteers-Help-Restore-Maritime-Forest-at-Cape-May-Point-State-Park.aspx*
- Jamaica Bay, NY: The Nature Conservancy and the National Park Service is undertaking a restoration project in the Jamaica Bay Wildlife Refuge with the help of volunteers. *https://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/newyork/places-preserves/jamaica-bay-wildlife-refuge-project.xml*
- Howard Beach, NY: A nature-based maritime forest and wetland are being constructed to protect a community at the southern end of Spring Creek by DEC in partnership with FEMA and USACE. *http://www.dec.ny.gov/about/104426.html*
- Staten Island and the Rockaways, NY: NYC Parks is leading maritime forest restoration projects at Wolfe's Pond Park, Staten Island; Conference House Park, Staten Island; and Rockaway Community Parks. *https://www.nycgovparks.org/.*

Factors to consider in design, construction and maintenance for restoration (if a natural feature) or construction (if a nature-based feature)

- Maritime forests near dunes need normal dune function and a consistent supply of sand to establish and grow (DNREC, 2000). Too much sand will bury the trees.
- Maritime forests take a considerable amount of space and time to form and may be difficult to do on a small scale. Restoration in NYC often has to consider a smaller area.
- Invasive species in New York's maritime forests often include (but are not limited to): Phragmites, bittersweet, Japanese honeysuckle, porcelainberry, wisteria, mugwort, etc. Managing these invasive species prior to replanting is crucial. A series of mechanical and chemical treatments is best for full eradication – two full growing seasons of treatment is often necessary to ensure success of native plantings.

Resources

- Plant community selection and installation phasing is an important consideration. Species planted in maritime forest restoration projects should be tolerant to salt spray, wind and drought. When possible, native seed or other genetic material should be used in propagation and planting. Seeding or plug planting is recommended for herbaceous communities, and woody plants are mostly likely to survive if planted from containerized stock (1-10 gallon). More guidance on maritime forest community composition can be found at *https://www.nycgovparks.org/greening/greenbelt-native-plant-center/habitat-species-lists/habitat-costal-maritime*

- Consult with the appropriate regulatory agencies before beginning any project near a maritime forest.

Sources

1. Cunniff, S., & Schwartz, A. (2015) Performance of Natural Infrastructure and Nature-based Measures as Coastal Risk Reduction Features. Retrieved from *http://www.edf.org/sites/default/files/summary_ni_literature_compilation_0.pdf*

2. de la Cretaz, A. L., & Barten, P. K. (2007). Land Use Effects on Streamflow and Water Quality in the Northeastern United States. Boca Raton, FL: CRC Press.

3. Delaware Department of Natural Resources and Environmental Control (DNREC). (2000). Delaware's Coastal Dunes. Document No. 40-70-03/03/09/03/03. Division of Soil & Water Conservation, Shoreline & Waterway Management Section and the University of Delaware Sea Grant College Program. Retrieved from *http://www.dnrec.delaware.gov/swc/SiteCollectionDocuments/Soil/DE%20Coastal%20Dunes.pdf*

4. Food and Agriculture Organization of the United Nations (FAO). (2005). Forests and Floods: Drowning in Fiction or Thriving on Facts? RAP Publication 2005/03. Rome: FAO and Center for International Forestry Research. Retrieved from *http://www.fao.org/docrep/008/ae929e/ae929e00.htm*

5. Gartner, T., McGray, H., Mulligan, J., Epstein, J., & Dinshaw, A. (2014). Adaptation: Forests as Water Infrastructure in a Changing Climate. In Forest Conservation and Management in the Anthropocene: Conference Proceedings. Proceedings RMRS-P-71 (pp. 313-337). Fort Collins, CO: U.S. Department of Agriculture, Forest Service. Rocky Mountain Research Station. Retrieved from *http://www.fs.fed.us/rm/pubs/rmrs_p071.html*

6. Gregory, S., Nisbet, T., & McKay, H. (2003a). Forests and Water. Sustainable Forestry in Brief. UK Forestry Commission. Retrieved from *http://www3.hants.gov.uk/forestsandwater.pdf*

7. Gregory, S., Nisbet, T., & McKay, H. (2003b). Forests and Flooding. Sustainable Forestry in Brief. UK Forestry Commission. Retrieved from *http://www3.hants.gov.uk/forestsandflooding.pdf*

8. Lopazanski, M. J., Evans, J. P., & Shaw, R. E. (1988). An Assessment of Maritime Forest Resources on the North Carolina Coast: Final Report Submitted to North Carolina Department of Natural Resources and Community Development, Division of Coastal Management. North Carolina Department of Natural Resources and Community Development, Division of Coastal Management.

9. Miller, C. F., & Pelligrine, M. (2009). Cape May Point State Park: A Case Study for Improving the Maritime Forests. Proceedings from Invasive Species in Coastal Dunes and Maritime Forests Conference, July 16–17, 2009, Georgian Court College. Retrieved from *http://www.nrcs.usda.gov/Internet/FSE_PLANTMATERIALS/publications/njpmcsy11007.pdf*

10. New York City Department of Parks and Recreation. (n.d.). Coastal Maritime Species List. Retrieved from *https://www.nycgovparks.org/greening/greenbelt-native-plant-center/habitat-species-lists/habitat-costal-maritime*

11. New York Natural Heritage Program. (2017). Online Conservation Guide for Successional Maritime Forest. Retrieved from *http://www.acris.nynhp.org/guide.php?id=10000*

12. Shirer, R., & Zimmerman, C. (2010). Forest Regeneration in New York State. Albany, NY: The Nature Conservancy. Retrieved from *http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/newyork/lands-forests/final-nys-regen-091410-2.pdf*

13. Virginia Institute for Marine Sciences (VIMS). (2017). Beaches and Dunes. VIMS Shoreline Studies Program. Retrieved from *http://www.vims.edu/research/departments/physical/programs/ssp/beaches/index.php*

14. Whitaker, J. D., McCord, J. W., Pulley, B., & Mullins, E. H. (2009). Best Management Practices for Wildlife in Maritime Forest Developments.

A.10 – Nearshore Area

What is the nearshore?

The nearshore area is an area of underwater lands that extend under and beyond waves breaking on the shoreline (Figure A.10-1 and Figure A.10-2). This area is important for longshore sediment transport, a process that moves sand parallel to the shoreline and is the primary means of sediment supply to many natural features in coastal areas (6 NYCRR 505, 1988). The nearshore area also acts as a sediment reservoir, forming sandbars and shoals (NAS, 2007).

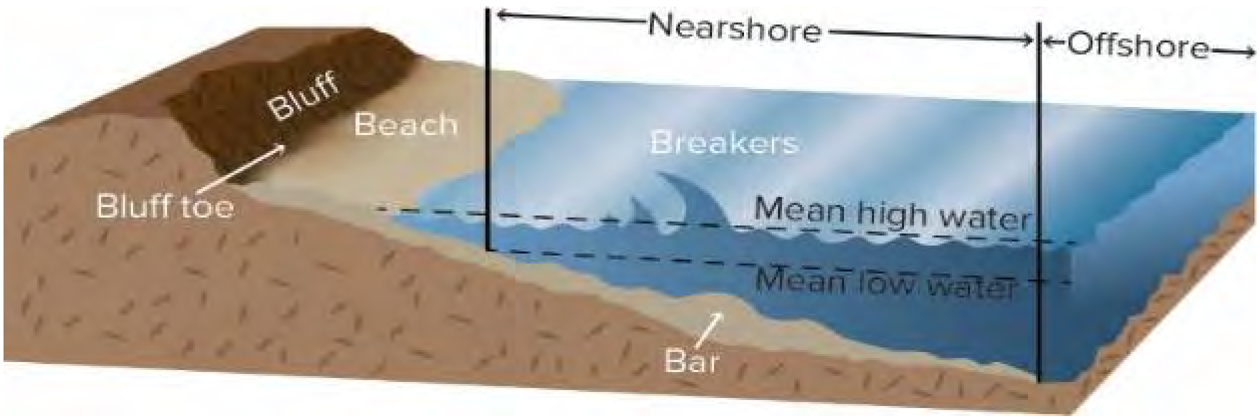
The nearshore area is influenced by offshore and longshore currents and wave action (NAS, 2007). Storm surge is an important source of sediment supply to the nearshore. It deposits sediment that builds and sustains wetlands. Sandbars that form in the nearshore area control the orientation of oncoming waves based on their length, width and depth. In lakes, these bars promote the development of winter ice-cap formations which can help to protect shorelines during winter storms (6 NYCRR 505, 1988). Growth of aquatic vegetation in the nearshore area helps to bind sediment and form a cohesive bottom (6 NYCRR 505, 1988). Nearshore areas can change suddenly and significantly due to sediment erosion and deposition as they absorb energy from waves and storms.

The NYS regulatory definition of the nearshore area is those lands underwater beginning at the mean low-water (MLW) line and extending waterward in a direction perpendicular to the shoreline to a point where minimal sediment transport or movement can be measured or observed (6 NYCRR 505, 1988) (Figure A.10-2). This is typically defined as the point where water depth reaches 15 feet, or a horizontal distance of 1,000 feet, whichever is greater.[27] DEC also classifies and regulates some marine nearshore areas for shellfish harvest based on water quality in those areas (*http://www.dec.ny.gov/outdoor/345.html*).

[27] To determine if a permit is required for a project at a specific location contact the Division of Environmental Permits in the appropriate DEC Regional Office.

Credit: © Antonio Graziano.

Figure A.10-1. Underwater nearshore lands are dynamic areas that are critical for sediment movement.
This is a nearshore area on the Grace Estate in Northwest Harbor, NY.



Credit: Adapted from US Navy.

Figure A.10-2. Cross-section of common features in the coastal onshore and nearshore area. The erosion of bluffs is an important source of sediment for beaches. Adequate sediment on beaches can reduce erosion at the bluff toe. Sediment deposited in nearshore and offshore areas by currents and waves can create bars and shoals that reduce wave height and velocity.

How do nearshore areas reduce risk?

Nearshore areas are typically part of a larger coastal system which may include barrier islands, beaches, bluffs, dunes, tidal wetlands, inlets and shoals. Conserving this larger natural system reduces risk in shore areas. Risk reduction will vary based on management of these individual features. Other measures may be needed to further reduce risk from large surge or flood events.

The nearshore provides the following risk reduction benefits:

- **Reduces water velocity**: The nearshore area often breaks offshore waves causing them to collapse. This action dissipates a substantial amount of wave energy before it is expended on beaches, bluffs or dunes reducing the risk from wave or wake energy and erosion (6 NYCRR 505, 1988). This reduces damages from current, wave or wake energy, erosion and storm surge. The nearshore reduces surge heights until the water depths exceed nearshore bottom friction effects. Vegetation in the nearshore area can reduce wave energy through friction.
- **Supplies sediment:** The nearshore area functions as a reservoir of sand, gravel and sediment that is eventually returned to beaches and shorelines. In turn, beaches protect upland areas by absorbing energy from waves, tides and currents that otherwise would be expended on the toes of bluffs, dunes or banks. The upland/beach/nearshore system stores and exchanges sediment in response to natural forces, reducing the impact of waves, currents and storm surges.
- **Stabilizes soil:** Aquatic vegetation in the nearshore area binds clays, silts and organic matter to form a cohesive bottom that resists the effects from wind and waves thus minimizing the risk from erosion (6 NYCRR 505, 1988).

Forces and conditions that nearshore areas can mitigate to reduce risks to people and communities

- Currents generally parallel to the shoreline causing damage from erosion, floating debris or the mobilization of ice
- Waves, wakes and surges generally perpendicular to the shoreline causing damage from erosion, floating debris or the mobilization of ice

Human activities that reduce or impair risk-reduction capacity

- Improper siting of offshore dredging sand sources may reduce sediment supply to adjacent areas and diminish the sand/sediment supplied to the beach leaving the shoreline more susceptible to erosion.
- The construction of hard structural features that reflect wave energy (e.g., bulkheads, revetments, seawalls) may reduce sediment supply and cause scouring of the nearshore.
- Shore perpendicular structures such as groins or jetties may interrupt sediment transport through the nearshore area.
- Removal of aquatic vegetation in the nearshore area will reduce friction and increase wave energy on the beach (Mackey, 2012).
- Boating and recreational activities too close to the shore or in shallow areas may disturb sediment and aquatic vegetation reducing friction provided by the nearshore area that slows wave energy (Mackey, 2012).
- The introduction of invasive species may alter food web dynamics, aquatic life and vegetation and bottom sediment, which may reduce sediment supply and increase erosion in the nearshore area (Mackey, 2012).
- Human activities on the upland and in the nearshore that introduce pollutants, reduce dissolved oxygen or increase turbidity can damage or kill protective vegetation and shellfish beds in the nearshore. Loss of these features can increase erosion.

Other benefits

The nearshore provides a range of other benefits, including the following:

- **Economic:** The nearshore area sediment transport supports and sustains beaches and barrier islands which are destinations for recreation and tourism that support the economies of coastal communities.
- **Habitat:** Nearshore areas provide habitat for plants fish and wildlife.
- **Community, culture and recreation:** Communities value nearshore areas for fishing, shellfishing, boating, swimming and wildlife-related recreation.

- **Water filtration/quality:** Nearshore areas provide nutrient sequestration or conversion that improves water quality (Bridges et al., 2015; NAS, 2007).
- **Carbon sequestration:** Where shoals support aquatic vegetation, tidal wetlands and submerged aquatic vegetation can sequester carbon.

Possible effects of changes in climate and water levels on nearshore areas

Sea-level rise/water-level change

- As water levels change, the nearshore area may shift, and the ecological function of the new nearshore area may change. Management of the sediment supply and invasive species may be needed to maintain the risk reduction benefits. Increases in water levels (e.g., sea-level rise) could cause nearshore area to shift to developed areas, which may require changes in land use (EPA, 1998).

Restored or nature-based nearshore area

Restored natural nearshore area: Nearshore areas can be restored by removing artificial barriers to water and sediment movement. It could also include removing barriers to overwashes.

Nature-based nearshore area: A nature-based nearshore area could be created by placing sediment on the interior bay side of a barrier island to create an artificial overwash. It may or may not include planting of vegetation. In-water structural components meant to stabilize or promote development of nearshore areas may not be considered nature-based features if they disrupt natural longshore, cross-shore or offshore sediment transport, or if they inhibit cross-island sediment transport on barrier islands.

Examples of locations where restored or nature-based nearshore areas have been implemented

- Bowman Bay, WA: A nearshore restoration in Washington removed armoring and revegetated the shoreline, engaging volunteers and restoring .6 acres of nearshore habitat *http://www.skagitmrc.org/projects/marine-habitats/bowman-bay-nearshore-restoration/*
- Snohomish County, WA: The Nearshore Beach Restoration Project included removal of a bulkhead on the beach, as well as restoring and regrading the beach to restore habitat. Native vegetation was planted, and additional sediment was placed to regrade the beach to a more natural profile. *http://www.snocomrc.org/projects/nearshore-restoration-project/*

Factors to consider in design, construction and maintenance for restoration (if a natural feature) or construction (if a nature-based feature)

- Activities in the areas of dredging and dredged material placement, including regulatory actions, come under the jurisdiction of the National Environmental Policy Act (NEPA). The USACE has developed guidance on dredging and material placement. (USACE, 2015)
- Maintenance of adequate sediment supply to the natural longshore sediment transport system should be considered in order to maintain the size, shape and effectiveness of the nearshore area.
- Native aquatic vegetation should be maintained or replanted to minimize the risk from erosion. Removal and monitoring of any invasive species may be needed in order to maximize the risk reduction benefits of the nearshore area.

Resources

- Consult the appropriate regulatory agencies before beginning any project in or near the nearshore area.

Sources

1. Bridges, T. S., Wagner, P. W., Burks-Copes, K. A., Bates, M. E., Collier, Z. A., Fischenich, C. J., ... & Russo, E. J. (2015). Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience (No. ERDC-SR-15-1). Vicksburg, MS: Engineer Research and Development Center, Environmental Lab.

2. Canada–United States Collaboration for Great Lakes Water Quality. (2016). Great Lakes Nearshore Framework. Retrieved from https://binational.net/2016/05/13/nearshore-eaux-littorales/

3. Davidson-Arnott, R. (2010). Introduction to Coastal Processes and Geomorphology (p. 210). New York: Cambridge University Press.

4. Mackey, S. D. (2012). Great Lakes Nearshore and Coastal Systems. In: U.S. National Climate Assessment Midwest Technical Input Report. J. Winkler, J. Andresen, J. Hatfield, D. Bidwell and D. Brown, coordinators. Great Lakes Integrated Sciences and Assessments (GLISA) Center. Retrieved from http://glisa.msu.edu/docs/NCA/MTIT_Coastal.pdf

5. National Academy of Sciences (NAS). (2007). Mitigating Shore Erosion Along Sheltered Coasts. Committee on Mitigating Shore Erosion along Sheltered Coasts. Ocean Studies Board, Division on Earth and Life Sciences.

6. Northeast Climate Science Center (NECSC). (2016). Climate Impacts on Atlantic and Great Lakes Nearshore Coastal Environments. Retrieved from

https://necsc.umass.edu/content/climate-impacts-atlantic-and-great-lakes-coastal-and-nearshore-environments

7. Title 6 of New York Codes, Rules and Regulations (NYCRR). (1988). Part 505: Coastal Erosion Management Regulations (p. 4 and 7).

8. U.S. Army Corps of Engineers (USACE). (2009). FIMP: Fire Island Inlet to Montauk Point New York Reformulation Study Draft Formulation Report (p. 78, 36–27, 32).

9. U.S. Army Corps of Engineers (USACE). (2015). Dredging and Dredged Material Management Engineer Manual. EM 1110-2-5025.

10. U.S. Environmental Protection Agency (EPA). (1998). Nearshore Waters and Your Coastal Watershed. EPA 842-F-98-007. Retrieved from http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=20050HE.txt

A.11 – Non-tidal (Freshwater) Wetlands

What is a non-tidal (freshwater) wetland?

Non-tidal wetlands are freshwater wetlands that are located inland and along the shorelines of the Great Lakes, Finger Lakes and large rivers. Wetlands are areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support a prevalence of vegetation typically adapted for life in saturated soil conditions (Clean Water Act, 1977). The presence of water-adapted vegetation is a primary indicator of a wetland. Non-tidal wetlands generally include swamps, marshes, bogs, embayments and similar areas, and are distributed widely, from floodplains in river valleys to headwater wetlands in high elevation mountains and ridges, to the wetlands that ring many areas of our Lake Ontario shoreline (Figure A.11-1 through Figure A.11-4).

The formation, persistence, size and function of non-tidal wetlands are controlled by the amount of precipitation and water movement on the landscape, both on the surface and underground, and as vegetation releases water through evapotranspiration. The functions of non-tidal wetlands are controlled by the following:

- Landscape position (elevation in the drainage basin relative to other wetlands, lakes and streams)
- Topographic location (depressions, flood plains, slopes)
- Presence or absence of vegetation
- Type of vegetation
- Type of soil
- The relative amounts of water flowing in and out of the wetland and how they move
- Local climate
- The chemistry of surface and ground water
- Land uses in adjacent areas

Furthermore, non-tidal wetlands along the Great Lakes shorelines including the Niagara and St. Lawrence Rivers - often referred to as Great Lakes coastal wetlands - are shaped by large-lake processes, including waves, wind tides, seiches, seasonal and long-term fluctuations in water levels and shoreline sediment movement (Maynard et al., 1997). In these ways, Great Lakes coastal wetlands differ significantly from both inland wetlands and tidal wetlands, and so key distinctions will be made where necessary within this document.

The NYS regulatory definition of a freshwater wetland is in the NYS Freshwater Wetlands Act (1975) (*https://www.dec.ny.gov/docs/wildlife_pdf/wetart24a.pdf*). NYS regulates actions within and near wetlands 12.4 acres or larger that are approximately shown on official Freshwater Wetlands Maps (*http://www.dec.ny.gov/lands/4937.html*).[28]

Credit: NYS DEC.

Figure A.11-1. Emergent marsh in New Paltz, NY.

[28] To determine if a permit is required for a project at a specific location contact the Division of Environmental Permits in the appropriate DEC Regional Office.

Credit: NYS DEC.

Figure A.11-2. Woodland pool in Black Creek Preserve, Esopus, NY.

Credit: NYS DEC.

Figure A.11-3. Non-tidal wetland on Black Pond Wildlife Management Area on Lake Ontario.

Credit: © The Nature Conservancy (Matt Levine).

Figure A.11-4. Buck Pond, a freshwater wetland on Lake Ontario.

Forces and conditions that non-tidal wetlands can mitigate to reduce risks people and communities

- Currents generally parallel to the shoreline causing damage from erosion, floating debris or the mobilization of ice
- Waves, wakes and surges generally perpendicular to the shoreline causing damage from erosion, floating debris or the mobilization of ice
- Precipitation or meltwater moving downhill to nearest waterbody causing erosion, temporary pooling and localized water damage
- Temporarily elevated water levels from surge, high river flows or high lake levels inland of the shoreline causing localized property damage

How do non-tidal wetlands reduce risk?

Non-tidal wetlands are typically part of a larger system which may include forests, streams, floodplains, riparian areas or on large lakes, nearshore areas, banks and dunes. Conserving this larger natural system reduces risk near non-tidal wetlands. Risk reduction will vary based on management of these individual features. Other measures may be needed to further reduce risk from large surge or flood events.

Non-tidal wetlands provide the following risk reductions benefits:

- **Reduce water velocity:** Wetland vegetation slows the flow of water (Moore and Larson, 1980; Mitsch and Gosselink, 1986). Wetlands absorb the energy of waves and slow stream or river currents (EPA, 2003). If large enough, they can help to reduce energy associated with seiches and wind-driven waves in the Great Lakes. A recent meta-analysis found that overall, wetlands reduce the severity and occurrence of flooding (Kadykalo and Findlay, 2016).
- **Absorb water:** Wetlands reduce flooding and associated erosion from overland flow by storing water in the soil. Wetlands can reduce the amount of water entering large streams at any one time, thereby reducing peak flows (Novitski, 1978; Mitsch and Gosselink, 1986). A strong correlation exists between the size of flood peaks and the percentage of a watershed occupied by lakes and wetlands (Carter, 1996). Wetlands in floodplains help to store and spread out water that overflows banks and reduce flood elevations (Sather and Smith, 1984; Mitsch and Gosselink, 1986, 2000). Cumulative loss of small wetlands and forest vegetation can result in significant changes in flood risk. For example, a Wisconsin study compared two watersheds, one with 40% lakes and wetlands and one with 10% lakes and wetlands. In the watershed with more lakes and wetlands, a 10% reduction in lakes and wetland area resulted in about 10% greater flood flows and erosion. In the watershed with fewer lakes and wetlands, a 10% reduction caused a 250 to 500% increase in flood flows and erosion (Novitski, 1982).
- **Stabilize sediment:** Wetlands reduce shoreline erosion by stabilizing sediments and absorbing and dissipating wave energy (EPA, 2003). Wetland plants and vegetation in adjacent areas hold soil in place with their roots. Wetlands capture sediment and store overland and stormwater flows.

Human activities that reduce or impair risk-reduction capacity

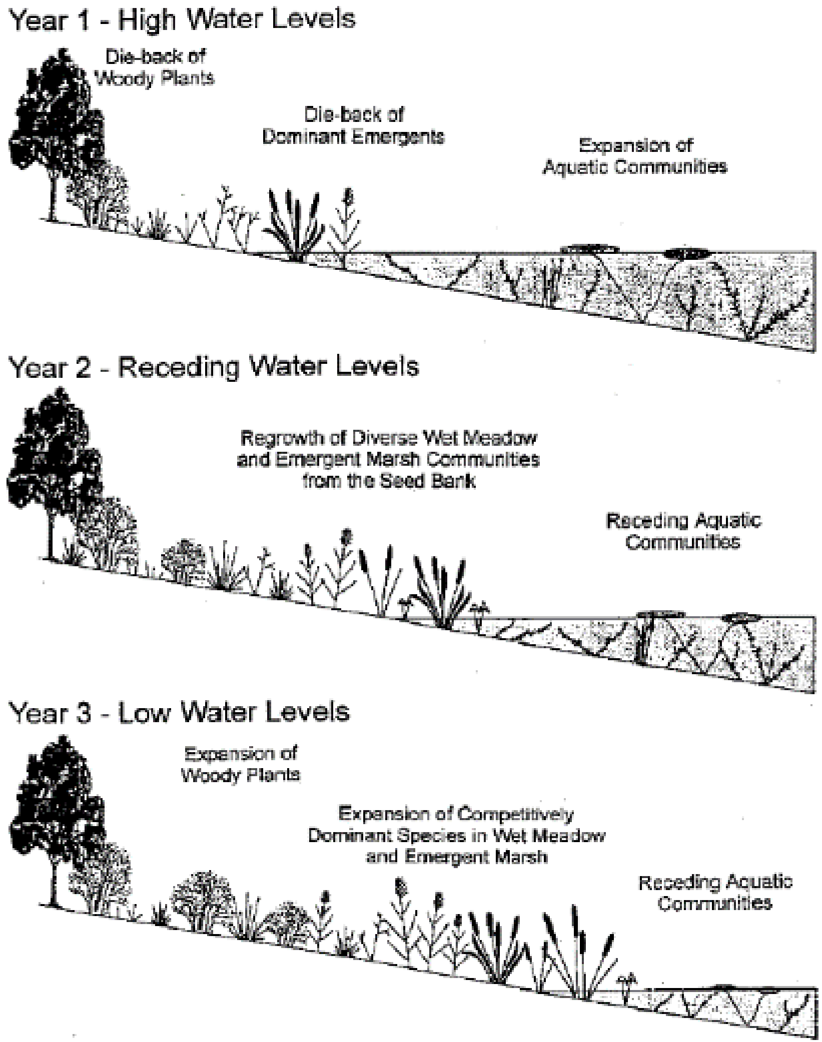
All Non-Tidal Wetlands

- Filling, ditching and degradation of wetlands and floodplains reduce their ability to hold flood waters and prevent erosion. Loss of wetlands can result in severe and costly flood damage in low-lying areas of a basin (Carter, 1996).
- Wetland adjacent areas provide flood storage capacity and stabilize soils. Wetlands are often compromised when their adjacent areas are cleared of native vegetation or covered by impervious or paved surfaces.
- It is essential to maintain the quantity of water in a wetland. Modifications to the depth, duration and frequency of surface and ground water flow to the wetland can cause adverse impacts.

- Nutrient enrichment from municipal sewage discharges, agricultural inputs and urban stormwater runoff can limit plant wetland plant diversity and therefore, risk reduction capacity (Maynard et al., 1997).
- Reduced light from overhanging structures, such as piers, docks and other structures can inhibit wetland vegetation growth.
- Introduction and/or proliferation of invasive species can change wetland vegetative structure and the capacity to reduce risk.

Great Lakes Coastal Non-Tidal Wetlands

- Wave and current reflection from shoreline hardening structures and boat wakes can erode wetlands.
- The construction of dikes, revetments or walls along the shore of a wetland reduces the extent and plant diversity of wetlands by removing the drier plant communities, which are slower to re-establish when lower levels return since the local seed source has been removed (Maynard et al., 1997). (Figure A.11-5)
- Activities that limit the availability of sediments for wetland accretion such as dam construction on tributaries, shoreline hardening and interference with sediment transport processes through the use of groins and jetties can slow or preclude wetland vertical growth and reduce barrier beaches that protect wetlands. Additionally, wetland area lost during a major storm is less likely to recover if there is insufficient sediment in the system to reestablish (Maynard et al., 1997).
- Dredging and channeling for boats, marinas and harbors reduces the extent and habitat diversity of wetlands (Maynard et al., 1997).
- Lake level management that limits the natural variability, frequency, timing and duration of water level changes can reduce the extent and productivity of wetlands and reduce the diversity of plant communities (Maynard et al., 1997). (Figure A.11-5)



Credit: Maynard and Wilcox, 1997.

Figure A.11-5. Simplified diagram of the effects of water-level fluctuations on coastal wetland plant communities of the Great Lakes.

Other benefits

Non-tidal wetlands provide a range of other benefits, including the following:

- **Economic:** Protection of wetlands to reduce flood risk along Otter Creek in Middlebury, VT saved $1.8 million in flood damage during Tropical Storm Irene (Watson et al., 2016). An Army Corps of Engineers study on acquisition of 8,500 acres of wetlands adjacent to the Charles River in Massachusetts estimated costs for engineered flood control measures at $100 million compared to a $10 million cost to acquire the wetlands (EPA, 2003). People also use many natural products from wetlands, including fish, wildlife and plants. Wetlands contribute to wildlife-dependent recreation, including wildlife watching and trapping fur-bearing wetland animals like muskrat, beaver and mink (EPA, 2003). Wildlife dependent recreation in NY is estimated to have an economic benefit of $5.5 million (DOI et al., 2012).

- **Habitat:** Wetlands serve as habitat, feeding areas and breeding and rearing areas for many species of fish and wildlife, including many rare species. More than one-third of the United States' threatened and endangered species live only in wetlands, and nearly half use wetlands at some point in their lives (EPA, 2003).

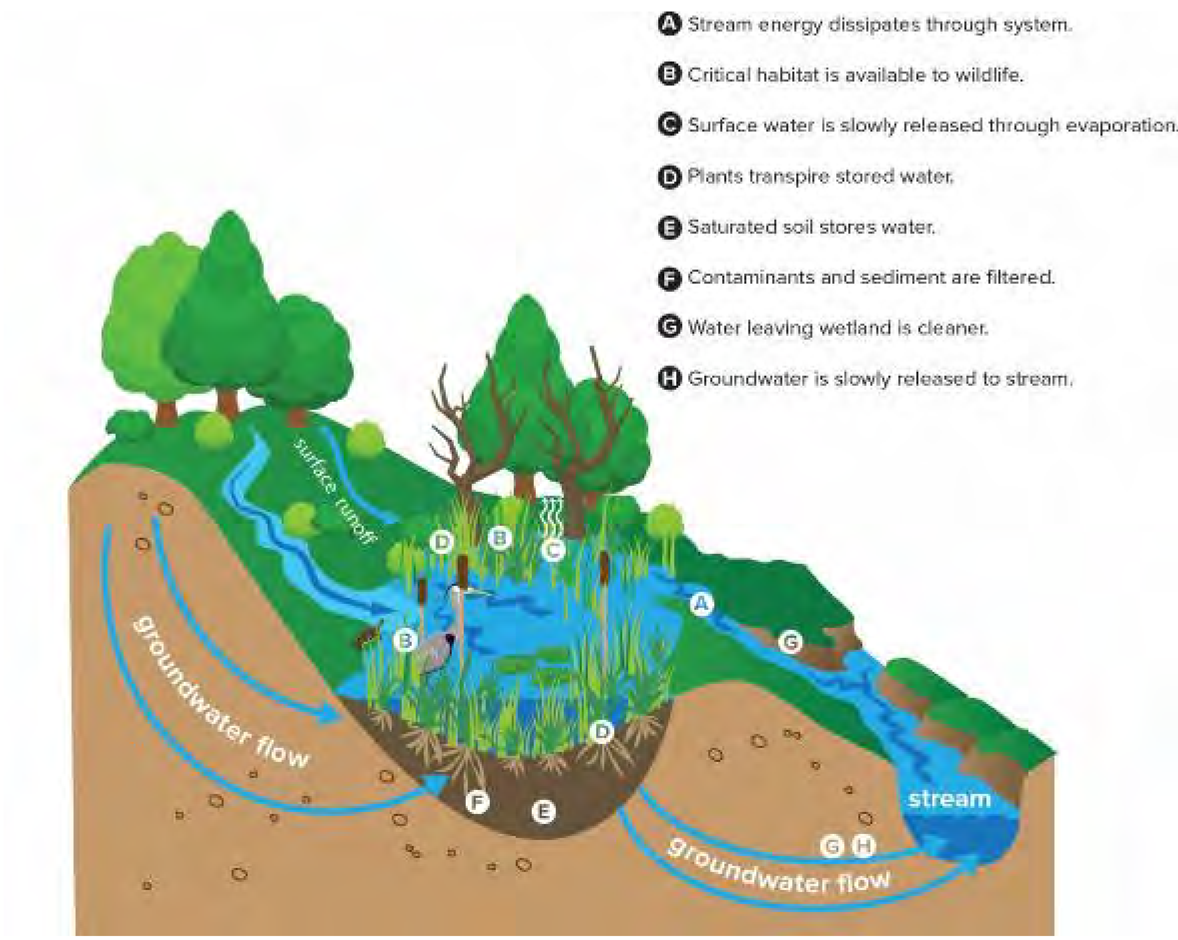
- **Drought Mitigation:** By increasing infiltration and groundwater recharge throughout a watershed, wetlands can help to maintain base flows in streams during drought conditions. They also can hold water and slowly release it back to surface and groundwater systems (Mitsch and Gosselink, 1986; Carter, 1996). The relationship of wetlands to groundwater varies, depending on their position in the landscape, the permeability of underlying soils, depth of the ground water table and other factors.

- **Extreme heat mitigation:** Vegetated natural areas can mitigate extreme heat and the urban heat island effect by providing shade and/or through the cooling effect of evapotranspiration, which releases water vapor (and thus heat energy) to the atmosphere.

- **Community, culture and recreation:** Communities value wetlands for scenery and providing access for boating, fishing, hiking, hunting, trapping and bird watching. Non-tidal wetlands are also closely coupled with some communities' sense of place and local cultural traditions.

- **Water filtration/quality:** Wetlands can serve as sinks, sources and transformers of nutrients and other chemical contaminants and they have a significant impact on downstream water quality and ecosystem productivity (Figure A.11-6).

- **Carbon sequestration:** Wetland vegetation sequesters carbon. Freshwater wetlands play an important role in the global budgets of carbon and the trace gases methane and nitrous oxide, all of which are greenhouse gases (Groffman and Taylor, 1995). The net amount of carbon sequestered in any individual wetland depends of a variety of environmental factors (Bridgham et al, 2013). Historically, the destruction of wetlands in North America through land-use change has led to large emissions of CO_2 and a loss of CO_2 storage capacity (Bridgham et al., 2006).



Credit: Adapted from: Turner et al. (2005).

Figure A.11-6. Wetlands are hydrologically connected to the surrounding watershed through surface and groundwater.
In addition to slowing and storing floodwaters, they perform many important functions, including removing and recycling nutrients and sediment and filtering and breaking down contaminants.

Possible effects of changes in climate and water levels on non-tidal wetlands

Changing Precipitation Patterns & Increased Temperatures

- Climate change will lead to changes in the hydrologic cycle (Erwin, 2009). However, the exact changes are uncertain and will be site-specific. Increased summer evapotranspiration and water deficits will reduce the extent of wetlands in the state, and seasonal wetlands will be particularly vulnerable (Rosenzweig et al., 2011).
- Great Lakes water levels naturally fluctuate and coastal wetlands are adapted to a variable water supply, however changes in the timing, duration and range of these fluctuations may reduce the areal extent and vegetative diversity of these wetlands.

Wetlands that are impeded from adapting to new water levels by manmade structures, steep slopes and/or unsuitable substrate may be most at risk (Mortsch, 1998).

- The extent and time period of ice cover will decrease, making coastal wetlands more vulnerable to erosion from winter storm winds and waves. However, the increased density of wetland vegetation due to increased carbon dioxide concentrations, may enhance wave attenuation and erosion control functions of some coastal and inland freshwater wetlands (Christie et al., 2012).

Stronger and more frequent storms

- Increased storm intensity can result in surges that compress wetland surfaces and deposit debris, damaging waves that erode wetland edges and large pulses of stormwater that may deposit contaminants, sediment and create unusually high turbidity. Depending on the circumstance, additional sediment deposition could add positively to wetland surface elevation or could result in excessive filling of a wetland causing reduced flood conveyance and storage capacity (Christie et al., 2012).

Restored or nature-based non-tidal wetland

Restored Non-tidal Wetlands: Wetland restoration improves the natural functions of an existing wetland or re-establishes a wetland that has been lost. Wetlands can be restored by removing barriers to water exchange, re-connecting formerly connected wetlands, removing invasive species, planting buffer vegetation, removing fill, restoring adjacent areas or fostering native communities.

Nature-based Non-tidal Wetlands: Nature-based wetlands are typically designed to replicate a specific wetland function such as treating wastewater, stormwater, acid mine drainage or agricultural runoff. In high energy areas, the planting of vegetation and the use of a low-profile sill or other nature-based coastal or stream techniques can be used to attenuate wave energy or strong currents.

Examples of locations where restored or nature-based non-tidal wetlands have been implemented

- Charles River, MA: Restoration of wetlands to reduce flood risk *http://www.nae.usace.army.mil/Missions/Civil-Works/Flood-Risk-Management/Massachusetts/Charles-River-NVS/*
- Otter Creek, Middlebury, VT: Protection of wetlands to reduce flood risk *http://www.uvm.edu/giee/?Page=news&storyID=23116&category=gund*
- Staten Island, NY: Creation of wetlands and "blue belts" to store and filter stormwater and reduce flooding in the Staten Island Bluebelt *http://www.nyc.gov/html/dep/html/dep_projects/bluebelt.shtml*

- West Brook wetland, Lake George, NY: Restoration of wetlands to filter stormwater http://www.lakegeorgeassociation.org/what-we-do/West-Brook-Conservation-Invitiative/west-brook.asp
- Buffalo, NY: Tifft Nature Preserve protection and wetland habitat improvements included *Phragmites* control and planted emergent vegetation to restore wetland habitat at a former shipyard (Figure A.11-7) http://www.tifft.org/tifft/scienceandresearch.

Credit: NYS DEC.

Figure A.11-7. Wetland restoration at the Tifft Nature Preserve in Buffalo, NY. Improvements included control of the invasive species, *Phragmites australis* (common reed) and planting of emergent native vegetation to restore wetland habitat at a former shipyard.

Factors to consider in design, construction and maintenance for restoration (if a natural feature) or construction (if a nature-based feature)

- Develop restoration objectives based on the site's capabilities, the level of effort that is expected to maintain wetland functions and how the site affects adjacent landscapes in the watershed (Christie et al., 2015).
- If the restoration project is planned for an area where a wetland has degraded over the course of time the root cause of the original degradation (such as impaired water quality and lack of sufficient natural sediment supply) should be understood and managed.
- Monitoring restoration success and adaptive management are integral to any restoration project.

Resources

- Refer to EPA's Principles of Wetland Restoration for additional recommendations: *https://www.epa.gov/wetlands/principles-wetland-restoration*.
- Specific guidance for restoration or enhancement of wetlands as mitigation projects pursuant to a permit can be found from state and federal agencies and various white papers, including Christie et al. (2015).
- See Sweeney et al. (2013) for landscape level approaches to wetland restoration. Tools for evaluating wetland flood risk reduction potential from that document can be found at: *http://www.eli.org/freshwater-ocean/tools-evaluating-flood-mitigation*.
- Consult the appropriate regulatory agencies before beginning any project near a non-tidal wetland or a restored or a restored or nature-based wetland project.

Sources

1. Association of State Wetland Managers. (2015). Wetlands and Climate Change: Considerations for Wetland Program Managers. Retrieved from *http://www.aswm.org/pdf_lib/wetlands_and_climate_change_consideratons_for_wetland_program_managers_0715.pdf*.

2. Bridgham, S., Megonigal, J., Keller, J., Bliss, N., & Trettin, C. (2006). The Carbon Balance of North American Wetlands. Wetlands, 26(4): 889–916.

3. Bridgham, S., Moore, T. R., Richardson, C. J., & Roulet, N. T. (2013). Errors in Greenhouse Forcing and Soil Carbon Sequestration Estimates in Freshwater Wetlands: A Comment on Mitsch et al. Landscape Ecology. doi: 10.1007/s10980-014-0067-2.

4. Carter, V. (1996). Technical Aspects of Wetlands: Wetland Hydrology, Water Quality, and Associated Functions. National Water Summary on Wetland Resources, U.S. Geological Survey Water Supply Paper 2425.

5. Christie, J., & Bostwick, P. (2012). Climate Change Adaptation Plan for Coastal and Inland Wetlands in the State of Michigan. Association of State Wetland Managers (ASWM), Inc. Retrieved from https://www.aswm.org/pdf_lib/michigan_wetlands_and_climate_change_report_final_403251_7.pdf

6. Christie, J., Stelk, M., Zedler, J., Weber, R., Lewis, R., Harcarik, T., & Teal, J. (2015). Wetland Restoration: Contemporary Issues & Lessons Learned. DRAFT. Retrieved from http://www.aswm.org/state_meeting/2015/wetland_restoration_whitepaper_032015.pdf

7. Clean Water Act (33 CFR § 323.2(c)). (1977).

8. Erwin, K. L. (2009). Wetlands and Global Climate Change: The Role of Wetland Restoration in a Changing World. Wetlands Ecology and Management, 17: 71–84.

9. Groffman, P., & Taylor, M. (1995). Non-Tidal Wetlands. In: Climate Change 1995: The IPCC Second Assessment Report: Scientific-Technical Analyses of Impacts, Adaptations, and Mitigation of Climate Change. R.T. Watson, M.C. Zinyowera, and R.H. Moss (Eds).

10. Kadykalo, A. N., & Findlay, C. S. (2016). The Flow Regulation Services of Wetlands. Ecosystem Services, 20: 91–103. doi: http://dx.doi.org/10.1016/j.ecoser.2016.06.005

11. Maynard, L., & Wilcox, D. A. (1997). Coastal Wetlands. Technical Report 58. Retrieved from http://digitalcommons.brockport.edu/tech_rep/58

12. Mitsch, W. J., & Gosselink, J.G. (1986). Wetlands. New York, NY: Van Nostrand Reinhold.

13. Mitsch, W.J., & Gosselink, J.G. (2000). The Value of Wetlands: Importance of Scale and Landscape Setting. Ecological Economics 35(1): 25–33.

14. Moore, I. D., & Larson, C. L. (1980). Hydrologic Impact of Draining Small, Depressional Watersheds. Journal of the Irrigation and Drainage Division, 106: 345–363.

15. Mortsch, L.D. (1998). Assessing the Impact of Climate Change on the Great Lakes Shoreline Wetlands. Climatic Change, 40: 391–416. Retrieved from https://link.springer.com/article/10.1023/A:1005445709728

16. New York State (NYS) Freshwater Wetlands Act § 24-301. (1975).

17. Novitski, P. (1978). Hydrologic Characteristics of Wisconsin's Wetlands and Their Influence on Floods, Stream Flow, and Sediment. Wetland Functions and Values: The State of our Understanding. American Water Resources Association.

18. Novitski, R. P. (1982). Hydrology of Wisconsin Wetlands. Wisconsin Geological and Natural History Survey Information Circular 40.

19. Rosenzweig, C., Solecki, W., DeGaetano, A., O'Grady, M., Hassol, S., & Grabhorn, P., Eds. (2011). Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation. Albany, NY: New York State Energy Research and Development Authority (NYSERDA).

20. Sather, J. H., & Smith, R. D. (1984). An Overview of Major Wetland Functions. U.S. Fish and Wildlife Service. FWS/OBS-84/18.

21. Sweeney, E., Womble, P., Wilkinson, J. B., Kihslinger, R., & Amsalem, J. (2013). A Handbook for Prioritizing Wetland and Stream Restoration and Protection Using Landscape Analysis Tools. Washington, D.C.: Environmental Law Institute.

22. Turner, B., Franklin, R., Journeay, M., Hocking, D., Franc de Ferrier, A., Chollat, A., Dunster, J., Whitehead, A., & Blair-Whitehead, D. G. (2005). Waterscape: Bowen Island. Geological Survey of Canada. Miscellaneous Report 88. Retrieved from *https://auma.ca*

23. U.S. Department of the Interior (DOI), U.S. Fish and Wildlife Service and U.S. Department of Commerce, & U.S. Census Bureau. (2012). 2011 National Survey of Fishing, Hunting and Wildlife-Associated Recreation. Retrieved from *https://www.census.gov/prod/2013pubs/fhw11-ny.pdf*

24. U.S. Environmental Protection Agency (EPA). (2003). America's Wetlands: A Vital Link between Land and Water. Office of Wetlands, Oceans, and Watersheds. Retrieved from *http://water.epa.gov/type/wetlands/upload/2003_07_01_wetlands_vital_wetlands.pdf*

25. Watson, K. B., Ricketts, T., Galford, G., Polasky, S., & O'Niel-Dunne, J. (2016). Quantifying Flood Mitigation Services: The Economic Value of Otter Creek Wetlands and Floodplains to Middlebury, VT. Ecological Economics, 130: 16–24. Retrieved from *http://dx.doi.org/10.1016/j.ecolecon.2016.05.015*

26. Wilcox, D. A. (2004). Implications of Hydrologic Variability on the Succession of Plants in Great Lakes Wetlands. Aquatic Ecosystem Health and Management, 7(2): 223–231. Retrieved from *https://www.researchgate.net/Simplified-diagram-of-the-effects-of-water-level-fluctuations-on-coastal-wetland-plant_fig2_239314976*

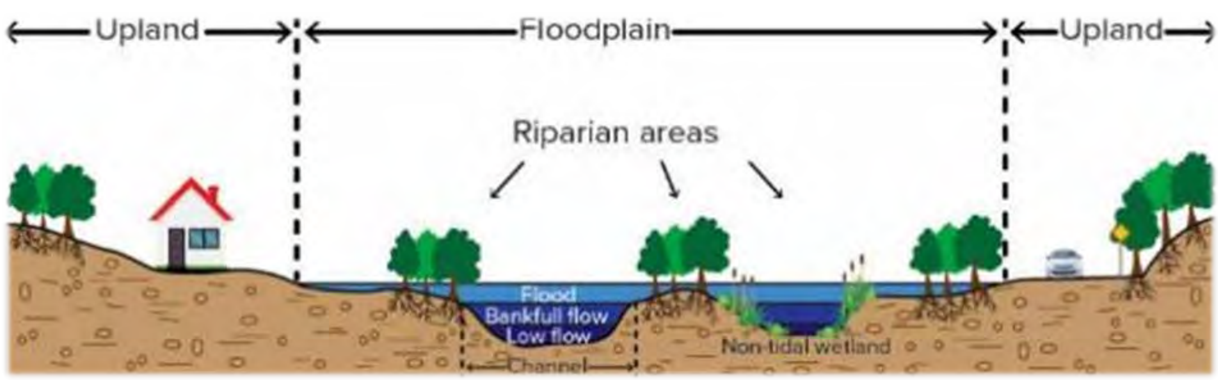
A.12 – Riparian Area

What is a riparian area?

Riparian areas are the lands bordering streams and rivers. They are transition zones between aquatic and upland areas that include the shoreline or bank and portions of the floodplain. Riparian areas have high levels of soil moisture, flood frequently and are inhabited by plants and animals that are adapted to wet conditions. Riparian areas reduce risk by reducing water velocity, absorbing water and stabilizing sediment (Figure A.12-1).

Riparian areas are dynamic areas formed and maintained by stream processes and by the interaction of changing water levels, erosion, sedimentation, vegetation and soils. They are likely to move or change significantly as energy and water from strong storms and other sources are absorbed. *For this reason, structures or assets sited within or near riparian areas are considered to be at greater risk.*

If left vegetated and undeveloped, a riparian area can serve as a buffer - a protective area between a body of water and human activity. Healthy vegetated buffers generally include diverse vegetation, including native trees, shrubs and grasses that provide stability, slow flood waters and intercept stormwater (Figure A.12-2).



Credit: NYS DEC.

Figure A.12-1. Cross-section of a floodplain and riparian areas.
Water elevations in the stream channel often correspond with water levels in riparian areas, such as wetlands and forests during low and bankfull flows. During flood conditions the floodplain, wetlands and riparian areas slow and store water and their vegetation slows water velocity. During low flow conditions wetlands and riparian areas release water back to the stream sustaining aquatic plants and animals.

Credit: NYS DEC.

Figure A.12-2. A healthy riparian area includes diverse types and sizes of native vegetation

How do riparian areas reduce risk?

Riparian areas are typically part of a larger natural system which may include streams, banks, floodplains, wetlands and forests. Conserving this larger natural system reduces risk in and near riparian areas. Risk reduction will vary based on management of these individual features. Other measures may be needed to further reduce risk from large surge or flood events.

Riparian areas provide the following risk reduction benefits:

- **Reduce water velocity:** The roots of trees and shrubs growing along the edge of a stream provide friction or roughness that can slow the velocity of water. Vegetated, undeveloped riparian areas allow floodwaters to access the floodplain where wide flat areas can slow down water (Figure A.12-3). Riparian areas preserve soil and preventing flood damage and erosion.
- **Absorb water:** Tree and shrub roots promote infiltration of water running off the land into the ground before it reaches the stream. Riparian floodplains can provide temporary water storage, allowing water to infiltrate to groundwater or removing water through plant uptake (Palmer et al., 2009). Plants also contribute to organic matter that

acts like a sponge to hold water and helps to maintain good porous soil (Hoorman and McCutcheon, 2005). Riparian wetlands are especially important for water storage.

- **Stabilize sediment:** The roots of trees and shrubs growing in riparian areas along the edge of a waterbody greatly increase bank stability. A riparian area with diverse vegetation can trap 80% to 90% of sediments transported from fields during flood events (Naiman and Decamps, 1997).

Credit: NYS DEC.

Figure A.12-3. An aerial view of the Esopus Creek in Ulster County.
Forested riparian buffers along streams help to absorb and slow flood waters, slow runoff, filter pollution, prevent soil erosion and improve habitat. The narrow riparian buffer on the left may provide some limited benefits, but the wider buffer on the right can provide much more. Wider buffers are especially important to support flood control and wildlife habitat.

Forces and conditions that riparian areas can mitigate to reduce risks to people and communities

- Currents generally parallel to the shoreline causing damage from erosion, floating debris or the mobilization of ice
- Waves, wakes and surges generally perpendicular to the shoreline causing damage from erosion, floating debris or the mobilization of ice
- Precipitation or meltwater moving downhill to nearest waterbody causing erosion, temporary pooling and localized property damage
- Temporarily elevated water levels from surge, high river flows or high lake levels inland of the shoreline causing property damage

Human activities that reduce or impair risk-reduction capacity

- Removal of vegetation, especially woody vegetation with deep roots and thick foliage can cause significant impairment to the ability of riparian areas to slow and absorb water.
- Stream channelization, dams, roads and other infrastructure built close to existing waterways can limit natural stream migration and disconnect the stream or river from the riparian area , floodplain and associated wetlands, limiting the ability of riparian vegetation to slow and absorb water. New infrastructure built near streams is also at higher risk of damage from flooding or erosion.
- Land use changes in the watershed that increase stormwater (like an increase in impervious or paved surfaces), while simultaneously decreasing the size of floodplains and riparian areas, can dramatically increase the volume of water in small streams in minor flood events. This can overwhelm the riparian area and result in dramatic erosion (Ehrhart, 2003).

Other benefits

Riparian areas provide a range of other benefits, including the following:

- **Economic:** Property loss can be prevented by regulating development in riparian floodplains. In one study, researchers estimated that over a 50-year timeframe, the cost of permanent floodplain conservation through riparian easements saved $85,000/mile compared to the cost of repeated streambank armoring in the same area (Kline, 2008). Undeveloped riparian floodplains provide economic benefits to public water by recharging aquifers and protecting water quality through filtration of runoff and sedimentation (Fischer and Fishenech, 2000). They also provide habitat for fish and wildlife populations, which contribute to hunting and fishing, bird and wildlife watching opportunities to support the local economy.

- **Habitat:** Riparian areas in natural floodplains provide terrestrial and aquatic habitat. Trees provide shade that moderates stream temperature creating conditions ideal for cool water species, such as trout. Trees also add organic material to streams, providing important habitat and nutrients to the aquatic community including fish, amphibians, reptiles and birds. Forested streams in floodplains also provide corridors for wildlife movement, creating passages for safe movement across the landscape and facilitation of genetic diversity between larger populations of mammals (Fremier et al., 2015). The greater the width of conserved natural floodplain and riparian areas, the greater the habitat value they can provide.

- **Drought mitigation:** Forested riparian areas create shaded areas where soil moisture can be maintained in drought conditions. Additionally, tree and shrub roots hold soil in place during drought events and prevent wind erosion and soil loss. Roots prevent water from running off immediately after storms and allow it to infiltrate and recharge groundwater. Healthy riparian forests can help maintain stream flow during droughts.

- **Extreme heat mitigation:** Forested riparian areas provide heat reduction to the stream channel and other bodies of water. Vegetated natural areas can mitigate extreme heat and the urban heat island effect by providing shade and/or through the cooling effect of evapotranspiration, which releases water vapor (and thus heat energy) to the atmosphere.

- **Community, culture and recreation:** Communities value riparian areas for scenery and providing access for fishing, swimming, hiking, boating, hunting, trapping and bird and wildlife watching. Riparian areas are also closely coupled with some communities' sense of place and local cultural traditions.

- **Water filtration/quality:** A well-vegetated riparian area slows overland runoff and filters sediments and sequesters or converts nutrients, pathogens and toxins from upland sources.

- **Carbon sequestration:** Vegetation in riparian areas absorb and store carbon and nitrogen by converting carbon dioxide and nitrogen into biomass (Palmer et al., 2009; Rheinhardt et al., 2012).

Possible effects of changes in climate and water levels on riparian areas

Stronger Storms

- Changes in intensity of extreme weather events are likely to have significant effect on riparian areas. Increased runoff can lead to erosion, sedimentation and damage to riparian zones and loss or changes in vegetation (NYSERDA, 2011, p. 175) (Ehrhart, 2003). However, human alterations, like paved surfaces, that alter the volume and flow of water and cause stream erosion have been identified as a more severe threat to riparian areas than the changes anticipated from climate change (Erhart, 2003).

Warmer temperatures

- Invasive pests, overgrazing, air pollution and changing temperatures can lead to changes in species composition (NYSERDA, 2011, p. 177), including the loss of woody species like riparian ash and hemlock to invasive insects such as Emerald Ashborer and Hemlock Wooly Adelgid. Human intervention may be needed to ensure that lost plant species will not be replaced by problematic invasive species (NYSERDA, 2011, p. 177), such as Japanese knotweed, which does not provide the same level of erosion control as native riparian species.

Short-term drought

- Drought, increased water withdrawal, channelization and incision of streams due to impervious surface can lead to lower water tables, which can cause drought stress resulting in less flood tolerant species and more invasive plants (Ehrhart, 2003).

Restored or nature-based riparian area

Restored Riparian Area: Riparian area restoration could consist of removal of impervious surfaces (i.e. pavement and buildings), re-planting of native trees and shrubs, removal of invasive or non-native plant species and use of geotextiles to hold sediment in place until vegetation becomes established (Figure A.12-4).

Nature-based Riparian Areas: A nature-based approach might include the above plus approaches to stabilize an eroding streambank through vegetated shoreline stabilization or natural channel design or use of constructed stormwater green infrastructure to manage erosion from overland flow. More information can be found in the feature descriptions for nature-based coastal, stream and constructed stormwater green infrastructure techniques.

Credit: NYS DEC.

Figure A.12-4. Girl Scout volunteers plant native trees and shrubs to restore a riparian area along the Monhagen Brook in Wawayanda, NY.
This effort, coordinated by the DEC Trees for Tribs program and the Orange County Soil and Water Conservation District, resulted in the planting of 260 trees and shrubs along 940 feet of stream.

Examples of locations where restored or nature-based riparian areas have been implemented

- Vermont has shown risk reduction benefits from using conservation easements to protect and preserve riparian areas (Kline, 2008).
- DEC's "Trees for Tribs" Program: This program is actively replanting riparian buffers in targeted high risk areas (*www.dec.ny.gov/animals/77710.html)*.
- NYC Watershed: Within the watershed of the New York City drinking water reservoirs, the Catskill Stream Buffer Initiative provides information and assistance to landowners in stewardship of their riparian areas through protection, enhancement, management or restoration (*http://catskillstreams.org/catskill-streams-buffer-initiative/)*.

- The Chesapeake Bay Program and the Great Lakes Program: These programs have programming and partnerships focused on riparian buffer planting (*www.chesapeakebay.net/managementstrategies/strategy/protected_lands* and *www.dec.ny.gov/docs/regions_pdf/glaai.pdf*).
- Mad River, VT: Efforts are underway to research and implement "agriculturally productive" riparian areas (*http://smallfarms.cornell.edu/2013/06/28/elderberry-and-beyond-new-options-for-river-lands-in-the-northeast/*)

Factors to consider in design, construction and maintenance for restoration (if a natural feature) or construction (if a nature-based feature)

- The potential for riparian areas to have a significant effect on flood attenuation and erosion control is site dependent. Multiple literature sources indicate that the wider area of riparian area that is protected or restored, the better it will be for supporting water quality, storm resiliency and wildlife habitat. Sweeney and Newbold (2014) provide a literature review documenting the functional potential of riparian areas based on case studies and note that 100 feet is the minimum width for multiple benefits. In order to ensure that the width will effectively provide the identified functions, projects need to consider slope, soils, vegetation and location within the watershed.
- When planting a riparian site, observations of existing native vegetation can help to indicate what could be planted. Making note of existing non-native vegetation can inform site preparation, including removal of invasive vegetation, which could threaten newly planted native species.
- Healthy, protected riparian areas are naturally self-sustaining. However, changes in upstream land use, precipitation, stream processes and increased temperatures can make management necessary. Riparian areas should be monitored for invasive species invasions, major changes in water availability and vegetation changes that would reduce effectiveness of risk reduction.
- When vegetation is added to a site, it needs to be protected from animal browse and human encroachment and from occasional stream and bank erosion. Fences and physical barriers can be used to protect newly planted woody vegetation from browse, trampling and competition from grasses and other vegetation. Individual plants can be protected by tree shelters or similar protection devices. Invasive plants may need to be managed to allow newly planted plants to thrive and other native plants to regenerate. Keeping vegetation low will also decrease vole damage to roots. Weed mats, careful mowing or weed-wacking may be used to help keep down competing vegetation during establishment. Herbicide may also be used to control weeds, but can only be applied by a certified applicator. Protection devices like tubes, mats and fences require regular maintenance. Plants should be watered regularly after planting for the first year and in

drought conditions to ensure establishment on site (Salon and Miller, 2012). Maintenance can be labor intensive and is recommended for at least five years after a riparian site is planted.

Resources

- Detailed guidelines for restoring riparian areas are available in Palone and Todd (1998) and Hairston-Strang (2005). New Jersey Resource Conservation and Development Program provides a group of fact sheets on assessment, planting and project descriptions (*http://northjerseyrcd.org/documents/#streamdocs*). NYS DEC's Trees for Tribs staff may be able to provide site specific guidance for restoration in riparian areas (see *http://www.dec.ny.gov/animals/77710.html* and *http://www.dec.ny.gov/chemical/106345.html*)
- Regional foresters, area biologists or local stream buffer coordination groups can also help with resources and knowledge to inform planting effective riparian buffers.
- Contact DEC's Trees for Tribs program for more information on restoring a riparian area.

Sources

1. Ehrhart, B. (2003). Riparian Areas. Functions and Strategies for Management. Washington, D.C., USA: National Academy Press. Environmental Conservation, 30(04): 408–409.

2. Fischer, R. A., & Fischenich, J. C. (2000). Design Recommendations for Riparian Corridors and Vegetated Buffer Strips (No. ERDC-TN-EMRRP-SR-24). Vicksburg, MS: Army Engineer Waterways Experiment Station, Engineer Research and Development Center.

3. Fremier, A. K., Kiparsky, M., Gmur, S., Aycrigg, J., Craig, R. K., Svancara, L. K., Goble, D., Cosens, B., Davis, F., & J.M. Scott. (2015). A Riparian Conservation Network for Ecological Resilience. Biological Conservation, 191: 29–37.

4. Hairston-Strang, A. (2005). Riparian Forest Buffer Design and Maintenance. Maryland Department of Natural Resources Forest Service.

5. Hoorman, J., & McCutcheon, J. (2005). Understanding the Benefits of Healthy Riparian Area. The Ohio State University Extension Fact Sheet LS-1-05.

6. Kennedy, C., Wilkison, J. B., & Balch, J. (2003). Conservation Thresholds for Land Use Planners. Environmental Law Institute.

7. Kline, M. (2008). A Guide to River Corridor Easements. River Management Program, Vermont Agency of Natural Resources, Department of Environmental Conservation. Retrieved from

http://www.watershedmanagement.vt.gov/rivers/docs/rv_RiverCorridorEasementGuide.pdf

8. Naiman, R., & Decamps, H. (1997). The Ecology of Interfaces: Riparian Zones. Annual Review of Ecology and Systematics. 28(1): 621–658. Retrieved from http://www.annualreviews.org/doi/abs/10.1146/annurev.ecolsys.28.1.621?journalCode=ecolsys.1

9. New York State Energy Research and Development Authority (NYSERDA). (2011) Responding to Climate Change in New York State. Retrieved from http://www.nyserda.ny.gov/climaid

10. Palmer, M. A., Lettenmaier, D. P., Poff, N. L., Postel, S., Richter, B., & Warner, R. (2009). Climate Change and River Ecosystems: Protection and Adaptation Options. Environmental Management, 44: 1053–1068.

11. Palone, R. S., & Todd, A. H. (Eds.). (1998). Chesapeake Bay Riparian Handbook: A Guide for Establishing and Maintaining Riparian Forest Buffers. U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. Retrieved from http://www.chesapeakebay.net/content/publications/cbp_13019.pdf

12. Rheinhardt, R. D., Brinson, M., Meyer, G., & Miller, K. (2012). Carbon Storage of Headwater Riparian Zones in an Agricultural Landscape. Carbon Balance and Management, 7: 4. doi: 10.1186/1750-0680-7-4.

13. Salon, P. A., & Miller, C. F. (2012). A Guide to: Conservation Plantings on Critical Areas for the Northeast. Corning, N.Y.: Big Flats Plant Materials Center.

14. Sweeney, B. W., & Newbold, J. D. (2014). Streamside Forest Buffer Width Needed to Protect Stream Water Quality, Habitat, and Organisms: A Literature Review. Journal of the American Water Resources Association, 50(3): 560–584.

15. Wenger, S. (1999). A Review of the Scientific Literature on Riparian Buffer Width, Extent, and Vegetation. Office of Publication Service and Outreach, Institute of Ecology, University of Georgia, Athens.

A.13 – Shellfish Beds and Reefs

What is a shellfish bed or reef?

A shellfish bed or reef is an intertidal or subtidal structure generated by the accumulation of living molluscan shellfish and dead associated shell from bivalves such as oysters, clams and mussels. Shellfish reefs and beds form three-dimensional structures in soft sediment, on rocky shores or in rubble in brackish conditions (Figure A.13-1).

DEC classifies areas where shellfish are found based on water quality in those areas. (*http://www.dec.ny.gov/outdoor/345.html).*[29]

Credit: NYC Parks.

Figure A.13-1. Oyster bed at low tide in Soundview Park in Bronx, New York.

How do shellfish beds and reefs reduce risk?

Shellfish beds and reefs are typically part of a larger coastal system which may include beaches, bluffs, nearshore areas, tidal wetlands and submerged aquatic vegetation. Conserving this larger natural system reduces risk along the shore. Risk reduction will vary based on

[29] To determine if a permit is required for a project at a specific location contact the Division of Environmental Permits in the appropriate DEC Regional Office.

management of these individual features. Other measures may be needed to further reduce risk from large surge or flood events.

Shellfish beds and reefs provide the following risk reduction benefits:

- **Reduce water velocity:** Shellfish reefs dissipate short waves and reduce wave energy in low to moderate storms in areas with small to moderate tidal ranges (Piazza et al., 2005). The size of intertidal shellfish reefs declines north of Chesapeake and Delaware Bays, however, there is still value from subtidal oyster beds providing friction and resistance to currents and waves.
- **Stabilize sediment:** Shellfish reefs can reduce erosion of shoreline or other natural features (e.g., SAV and wetlands), but are not capable of reducing substantial waves (Piazza et al., 2005).

Forces and conditions that shellfish beds and reefs can mitigate to reduce risks to human assets

- Currents generally parallel to the shoreline causing damage from erosion, floating debris or the mobilization of ice
- Waves, wakes and surges generally perpendicular to the shoreline causing damage from erosion, floating debris or the mobilization of ice

Human activities that reduce or impair risk-reduction capacity

- Poor water quality, harmful algal blooms, low oxygen and sedimentation can cause suboptimal conditions for bivalve growth, reproduction and survival.
- Shellfish beds and reefs can be directly damaged due to dredging, drilling or filling.
- Aggressive fishing practices such as overharvest can reduce the shellfish population and its reproductive capacity. Naturally productive oyster systems frequently become substrate-limited due to removal of shell without replacement.

Other benefits

Shellfish beds and reefs provide a range of other benefits, including the following:

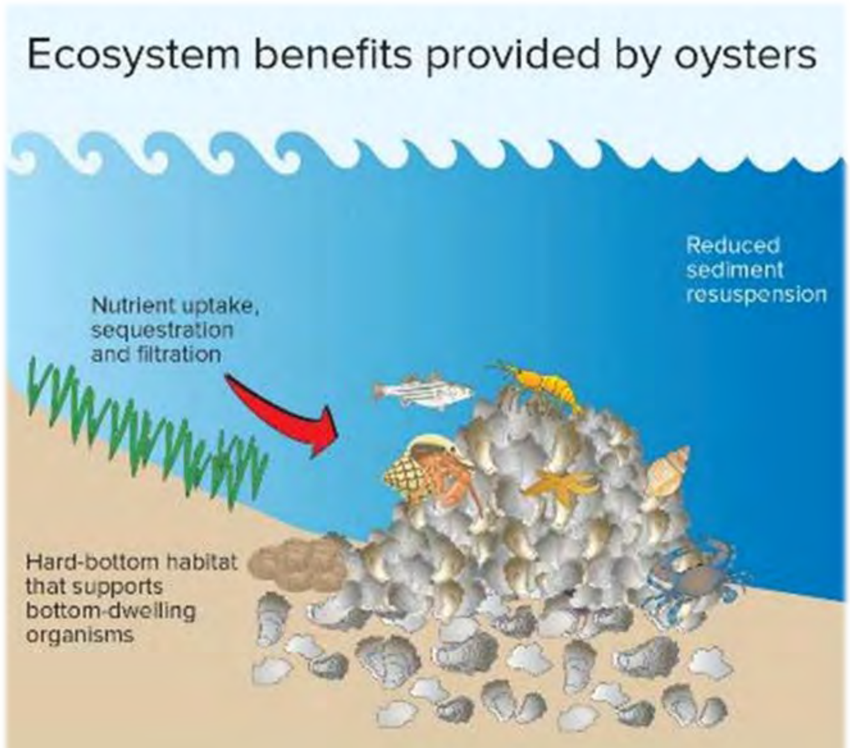
- **Economic:** Shellfish reefs can provide direct economic benefits from the harvest of marketable shellfish. They also **provide** economic benefits to other industries, such as commercial and recreational fisheries and nature and wildlife tourism. It is illegal to harvest shellfish from uncertified waters.

- **Habitat:** Shellfish reefs provide nursery and refuge habitat for a range of marine and estuarine species including polychaetes (e.g., marine worms), crustaceans (e.g., crabs), fish and other mollusks (e.g., snails). (Figure A.13-2)

- **Community, culture and recreation:** Communities value shellfish beds and reefs for fishing and bird watching. Coastal communities derive economic benefits from these resources through harvest or local aquaculture industries (in state-certified waters) (Figure A.13-3), fishing and bird watching. Many communities have a strong tradition of recreational harvest of shellfish that reinforces community cultural heritage.

- **Water filtration/quality:** Oysters are filter feeders, consuming phytoplankton (free-swimming algae) and improving water quality while they filter their food from the water column. Their filter feeding and their reef structure's ability to reduce water velocities can reduce sediment suspension. They take up nutrients, but also release them back to the water column and sediments. Once in sediments microbes break it down and release s nitrogen gas to the atmosphere instead of fueling algae blooms. Additionally, they are substrate for other hard bottom benthos to attach, such as mussels and slipper shell snails, which are also good filter feeders. Ribbed mussels which live in intertidal areas and wetland edges can consume very small plankton, such as the organisms that cause brown tide, which oysters will not (Figure A.13-2).

- **Carbon sequestration:** Shallow subtidal reefs and salt marsh-fringing reefs absorb carbon, especially when dominated by organic-rich material and associated with moderate vertical growth (Smith, 2012).



Credit: Adapted from the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu).

Figure A.13-2. Oyster beds or reefs provide habitat for aquatic life like crabs, fish and shrimp.
Because they feed by filtering water they can remove excess nutrients and contaminants. Their structures can reduce wave action, which can reduce the amount of sediment in the water column and improve water clarity.

Credit: © The Nature Conservancy.

Figure A.13-3. Oysters harvested on Long Island.

Possible effects of changes in climate and water levels on shellfish beds and reefs

Stronger Storms

- Prolonged "freshets" or periods of freshwater flow in streams and rivers that flow into estuaries, can impair oyster survival if the salinity becomes too low. More intense rainfall events will likely result in longer "freshets" in our region.
- Long-term establishment of any intertidal oyster reef structure in New York waters will be hindered by severe weather events. During winter months, oysters exposed at low tide will not be able survive icing events and sustained low temps.

Warmer Temperatures

- Increasing water temperatures are allowing biotic pathogens to expand their range northward reaching native populations that lack natural resistance. This leads to outbreaks of disease such as Dermo, a parasite with prevalence in higher temperature and salinity waters that quickly spreads from oyster to oyster, causes diminished growth, reproductive decline and death (Hofmann and Ford, 2012).

Ocean Acidification

- As carbon dioxide in marine waters increases, ocean pH decreases or becomes more acidic. This makes it harder for shellfish to absorb the calcium carbonate they need to build their shells. This has effects on bivalve shell formation and impairs larval development, reducing recruitment of oysters. In some cases, the population can decline below a point of recovery, when reproduction and recruitment will not overcome the mortality of adults in the population.

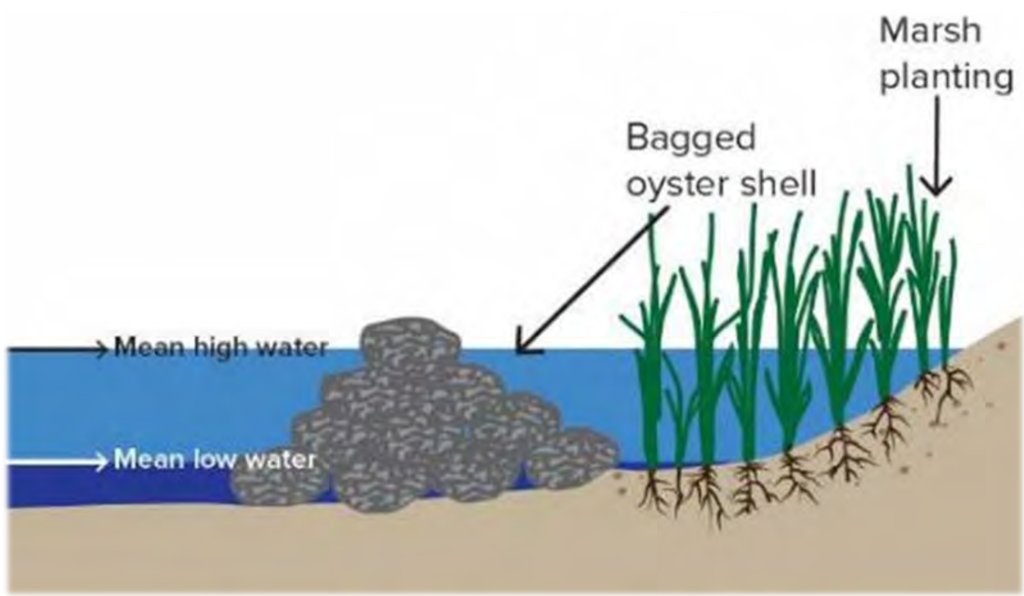
Restored or nature-based shellfish beds or reefs

Restored Natural Shellfish Beds and Reefs

Shellfish beds or reefs can be restored by seeding of shellfish larvae and improving water quality. Shellfish enhancement measures (adding juvenile or adult shellfish) to bottom habitats have been used to supplement declining natural populations. Both oysters and ribbed mussels can be used to form or enhance reef structures.

Nature-based Shellfish Beds and Reefs

Nature-based shellfish reef restoration can include components such as bagged or loose shell and other artificial substrates or manufactured concrete structures (e.g. reef balls™ or oyster castles™) which encourage shellfish and other marine organisms to colonize the surfaces and grow. These components are often used as low-profile wetland sills that attenuate wave action on tidal wetlands, as illustrated in Figure A.13-4. Examples of other nature-based coastal strategies can be found in Nature-based Coastal Techniques.



Credit: Adapted from North Carolina Division of Coastal Management.

Figure A.13-4. Oyster shells in net bags, used as a low-profile sill.

Examples of locations where restored or nature-based shellfish beds and reefs have been implemented

- New York Harbor, Jamaica Bay and western Long Island Sound: There have been attempts to restore pilot scale oyster reefs with mixed success (Grizzle et al., 2013; Lodge et al.; 2015; NYC DEP, 2011).
- Many Towns on Long Island have oyster and seed clam programs to promote harvest.
- Hudson River, NY: Based in part on assessments by Levinton et al. (2011), experimental substrate-based restoration is underway in the Tappan Zee/lower Haverstraw region of the Hudson River Estuary.
- Chesapeake Bay, MD: NOAA has supported restoration efforts in the Chesapeake Bay area. *http://chesapeakebay.noaa.gov/oysters/technical-aspects-of-oyster-restoration*

Factors to consider in design, construction and maintenance for restoration (if a natural feature) or construction (if a nature-based feature)

- Focus restoration efforts in "open/shellfishable" waters of the state when restoring consumable shellfish, to decrease risk of human health issues. Generally, it is the policy of the DEC to not allow the utilization of commercially important species, such as oysters, in waters of the state that are classified as "uncertified," and thus closed to any harvest of shellfish for human consumption. It is preferred that these installations be done in certified areas. In areas closed to shellfisheries, seek to restore alternative bivalve species, such as ribbed mussels, which are not harvested for human consumption. To determine the sanitary classification of your site and check to see if your project site is located in an area closed to shellfish harvest (uncertified), see the DEC website at *http://www.dec.ny.gov/outdoor/345.html* .
- Seeding requires state permits, pre- and postproject evaluation and monitoring. Additional permits may be required by the local municipality and DEC (e.g. license to collect and possess, shellfish importation permit if using an out-of-state source of shellfish, etc.).
- Large scale oyster restoration in New York Harbor is currently hampered by water quality issues affecting both survivability and harvest of potentially marketable species. Ribbed mussels may be preferred for use in shellfish restoration projects where water quality and edibility is a concern.
- Oyster beds situated in intertidal areas grow faster because the oysters stack on top of each other in clusters. The underwater parts of an intertidal oyster reefs can grow rapidly, but the crest of the reef grows more slowly, and can't grow faster than sea levels rise.
- In the brackish Hudson River estuary, rely on settlement of native spat, which has been demonstrated to be genetically unique to the Hudson River and possibly adapted to

lower salinity environments. Seek to restore only in deep waters where salinity is higher and more stable.

- If using shell for substrate, it must be native material allowed to dry for a period of 6 months in 2-3' piles before use to avoid transmittal of parasite or other pathogens.
- Projects designed to support naturally productive shellfish beds need to include appropriate considerations for how water quality, water circulation, and benthic substrate may affect survival.

Restoration Location

- It is generally recommended that projects conduct pilot testing phase in candidate restoration areas in order to evaluate reef or bed feasibility and shellfish performance in terms of health and productivity.
- Locations should be conducive to larval oyster development.
- Sediment type should be appropriate so that placement does not sink and sedimentation in area does not hinder production or bury structure.
- Water quality should be appropriate for optimal survival;
- Currents and wave energy should be such that structure is not eroded.
- Fouling or growth on substrate in high nutrient environments, or excessive deposition, can also inhibit recruitment and sustainability of a reef structure
- Navigation or other uses of the waterway should be considered when placing a shellfish reef.

Resources

- Monitoring should follow accepted guidance from Baggett et al. (2014).
- Consult with NYS DEC's Marine Resources prior to undertaking any shellfish restoration or reef project.

Sources

1. Baggett, L. P., Powers, S. P., Brumbaugh, R., Coen, L. D., DeAngelis, B., Greene, J., Hancock, B., & Morlock, S. (2014). Oyster Habitat Restoration Monitoring and Assessment Handbook. Arlington, VA: The Nature Conservancy.

2. Brandon, C. M., Woodruff, J. D., Orton, P. M., & Donnelly, J.P. (2016). Evidence for Elevated Coastal Vulnerability Following Large-Scale Historical Oyster Bed Harvesting. Earth Surface Processes and Landforms, 41(8): 1136–1143.

3. Coen, L. D., Grizzle, R. E., Lowery, J. L., Paynter, K. T., Jr., Thomas, J., & Nygard, J. (2007). The Importance of Habitat Created by Molluscan Shellfish to Managed Species along the Atlantic Coast of the United States.

4. Grizzle, R., Ward, K., Lodge, J., Suszkowski, D., Mosher-Smith, K., Kalchmayr, K., & Malinowski, P.. (2013). Oyster Restoration Research Project (ORRP) Final Technical Report. Submitted to: Hudson River Foundation, New York, NY. Retrieved from *http://www.oyster-restoration.org/oyster-restoration-research-reports/ and http://www.hudsonriver.org/?x=orrp*

5. Hofmann, E. E., & Ford, S. E. (2012). An Introduction to Ecology of Infectious Diseases—Oysters and Estuaries. Journal of Marine Research, 70(2): I.

6. Levinton, J., Doall, M., Starke, A., & Kuhn, S. (2011). Restoration of Oysters to the Tappan Zee-Haverstraw Bay Region: Final Report to NYS Department of Environmental Conservation. NYS DEC-SBU MOU no. AM06800.

7. Lodge, J., Grizzle, R., Coen, L., Mass Fitzgerald, A., Comi, M., & Malinowski, P. (2015). Community Based Restoration of Oyster Reef Habitat in the Bronx River: Assessing Approaches and Results in an Urbanized Setting. Final Report of the NOAA/WCS Regional Partnership Grant, New York, NY.

8. New York City Department of Environmental Protection (NYC DEP). (2011). DEP Launches Pilot Ribbed Mussel Ecological Project. Retrieved from *http://www.nyc.gov/html/dep/html/press_releases/11-73pr.shtml#.VwbkbP72a00*

9. Peterson, C. H., & Lipcius, R. (2003). Conceptual Progress Towards Predicting Quantitative Ecosystem Benefits of Ecological Restorations. Marine Ecology Progress Series 264: 297–307.

10. Piazza, B. P., Banks, P. D., & La Peyre, M. K. (2005). The Potential for Created Oyster Shell Reefs as a Sustainable Shoreline Protection Strategy in Louisiana. Restoration Ecology, 13(3): 499–506.

11. Smith, P. (2012). Oysters Could Combat Global Warming. Coastal Review Online: A Daily News Service Covering North Carolina's Coast. Retrieved from *http://www.coastalreview.org/2012/09/oyster-reefs-could-combat-warming/*

A.14 – Shoals or Bars

What is a shoal or bar?

A shoal or bar refers to "a natural, subaqueous ridge, bank, or bar consisting of, or covered by, sand or other unconsolidated material, rising from the bed of a body of water (e.g., estuarine floor) to near the surface. It may be exposed at low water." (USDA NRCS, 2013) Shoals and bars consist of sediments carried by flowing water along shorelines or through inlets, and deposited in locations where the current speeds slow to the point that sediment can no longer be carried. They can accumulate in inlets, lakes, streams, rivers and tidal areas. Shoals and bars reduce risk by reducing water velocity and supplying sediment to other natural features.

There are several types of shoals. A delta is a type of shoal that is created when sediment carried by a river enters a slower moving water body, such as an ocean, lake, or estuary. The ebb-tidal shoal (or delta) is a sand mass that accumulates seaward of the mouth of an inlet or river. It is formed by outgoing ebb tidal currents and is modified by wave action and longshore currents. The flood tidal shoal is an accumulation of sediment deposited by waves and currents flowing landward into and through an inlet. Flood tidal shoals accumulate at the landward opening of an inlet and are shaped by tidal, river and lake currents (USACE, 2002; FGDC, 2012). Offshore bars form at locations where waves retreating from the beach encounter offshore sediment transport processes, depositing sandy grains where outflow energies and incoming waves neutralize current speeds. River bars form at eddies, channel bends or in the shadow of protective features where transported sediment or "bedload", is deposited when current speeds slow below speeds necessary for transporting mobilized grain sizes (Figure A.14-3).

Shoals are in constant motion and shaped by waves and currents. They are likely to move or change significantly as energy and water from strong storms and other sources are absorbed.

Shoals are frequently associated with adjacent wetland areas and accumulating shoals may form suitable substrate for colonization by wetland vegetation. Shoals are identified on NYS tidal wetland regulatory maps (*http://opdgig.dos.ny.gov*).[30]

[30] To determine if a permit is required for a project at a specific location contact the Division of Environmental Permits in the appropriate DEC Regional Office.

Map Credit: NYS DOS.

Figure A.14-1. Aerial image of a natural shoal.
Basemap sources: ESRI, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo and the GIS User Community.

Credit: NYS DOS.

Figure A.14-2. Shoals can form on the ebb and flood tidal deltas of coastal inlets.

Credit: NYS DEC

Figure A.14-3. A gravel bar on the Delaware River in New York.

How do shoals reduce risk?

Shoals are typically part of a larger natural system which may include beaches, bluffs, dunes, nearshore areas, tidal wetlands and inlets or a freshwater system in a lake, stream or river. Conserving and maintaining this larger natural system reduces risk near shoals. Risk reduction will vary based on the management of individual natural features. Other measures may be needed to further reduce risks from large surge or flood events.

Shoals provide the following risk reduction benefits:

- **Reduces water velocity:** The sand shoals associated with ebb-tidal deltas may act as natural offshore breakwaters, breaking waves and reducing wave energy on landward beaches (FitzGerald, 1988). The shallow shoal area slows wave and current velocities and breaks incoming waves and surges in inlets and estuaries (Figure A.14-4). Shoals in rivers and streams slow water velocities, helping balance flow rates and sediment bed loads. Shoals adjacent to wetlands reduce incoming wave and current energy, helping to stabilize sediment and vegetation.

- **Supplies sediment:** Shoals store sediment that supply adjacent features during periods of heightened energy in the water column, such as storms. Shoals reduce erosion and help stabilize banks, beaches and barrier islands by providing sediment sources to replenish natural features that reduce risk. In certain conditions shoals may contribute sediment to adjacent beaches (Schwab et al., 2014).

Credit: NYS DOS.

Figure A.14-4. Natural shoals often occur in inlets.
These shoals are in Goldsmiths Inlet in the Town of Southold, NY. The shallow slope, rock and gravel and vegetation create friction that can reduce water velocity.

Forces and conditions that shoals can mitigate to reduce risks to people and communities

- Currents generally parallel to the shoreline causing damage from erosion, floating debris or the mobilization of ice

- Waves, wakes and surges generally perpendicular to the shoreline causing damage from erosion, floating debris, or the mobilization of ice

Human activities that reduce or impair risk-reduction capacity

- Installation of groins, jetties and other hard structures can impede the natural formation of shoals by not allowing sand or sediment to migrate. They can reflect wave energy and scour or erode shoals. Shoals may erode if incoming sediment from upstream or updrift sources is eliminated. Hard structures can also cause the formation of shoals and bars in areas they might not naturally occur by affecting sediment transport (Kennett, 1982).
- Dredging and removal of sediment in a shoal, bar or delta can remove sediment that would migrate to adjacent features over time or form the base over which other incoming sediment is transported. Dredging along shorelines or offshore in a river, bay, lake and ocean creates sediment sinks (deficits) which must be filled by incoming sediment before normal sediment transport can resume. Dredged material should be placed down drift of the inlet or shoal to allow it to continue through the system.
- Artificially high engineered dunes on barrier islands may eliminate pathways for bay-side shoal creation by eliminating overwash or cross-shore sediment transport.
- Removal or destruction of protective vegetation, boat wake erosion or keel damage and drainage discharge or water diversion onto the shoal may erode shoals.
- Shoals that form as a result of incoming sediment at a breach can be eliminated over time if the inlet is artificially closed.
- Excess soil erosion on shorelines may stimulate the accumulation of shoals. Active management measures, such as dredging, and/or improved watershed planning, may be needed to maintain adequate channel depth to sustain navigation.

Other benefits

- **Economic:** Shoals reduce damage from erosion by supplying sediment and from surge and waves by promoting barrier island formation (Leatherman, 1979)
- **Habitat:** Provides habitat for burrowing organisms such as crabs and clams, forage areas for bottom feeders such as flounder and sand sharks and a base for aquatic vegetation. Sediment storage and exchange supports tidal and non-tidal wetland formation in back bays. Piping plovers, which are federally threatened and NYS endangered, have also been known to utilize shoals for nesting, loafing or feeding.
- **Community, culture and recreation:** Fishermen may use these features as habitat for game fish or for access to game fish in adjacent areas.
- **Water filtration/quality:** Shoals that support tidal wetlands have the ability to protect water quality by trapping sediments and contaminants.

- ➔ **Carbon sequestration:** Shoals that support tidal wetland and emergent and submerged aquatic vegetation can sequester carbon. Marine-associated wetlands often have quite high soil carbon sequestration rates and low methane emissions (Bridgham et al., 2006; Pendleton et al., 2012).

Possible effects of changes in climate and water levels on shoals

Sea-level rise/water level change

- If natural coastal sediment transport processes are maintained many shoals should be able to keep pace with sea-level rise and natural water level fluctuations. Construction of shore defense structures that reduce sediment supplies or affect sediment transport would inevitably compromise shoals.

Restored or nature-based shoal

Restored Natural Shoals: A shoal can be restored by inlet shallowing (placing fill in the channel), nearshore deposit of sand, regrading of the nearshore area or by removal of unnatural barriers to longshore or cross-shore sediment transport. Shoals can be restored on the bay side of a barrier island to mimic a natural washover, for instance where human actions may have disrupted natural processes.

Nature-based Shoal: A shoal may be created, where it has not historically existed, by placing sediment in the water in a location where it will tend to be stable, such as on bay side of a barrier island to mimic a natural overwash deposit. Artificial overwash may or may not include planting of vegetation, or vegetation may colonize the shoal, creating a submerged aquatic vegetation bed. The use of in-water structures to stabilize or promote development of shoals may remove a project from the nature-based feature classification if natural sediment transport is disrupted by the structure(s). More information can be found in the nature-based coastal and stream techniques feature descriptions.

Examples of locations where restored or nature-based shoals have been implemented

- An effort is proposed to mimic natural overwash processes by adding sediment to nearshore areas on the bay side of the barrier island system under the FIMP: Fire Island Inlet to Montauk Point Reformulation Study, Draft Formulation Report (USACE, 2009).
- Creation of a fish spawning shoal from an artificial rock island and extension of the shoal with rock and cobble is underway in Lake Ontario by the Hamilton Port Authority (SOGL, 2017).

- Frog Island Restoration, Niagara River– A remnant riverine wetland has been restored to provide emergent and submergent wetland habitat areas using low profile wetland sills and nature-based shoals (Figure A.14-5) (NYPA, 2010).

Credit: P. Leuchner.

Figure A.14-5. Use of wetland sills to capture sediment and support wetland development and habitat improvement in the Niagara River.

Factors to consider in design, construction and maintenance for restoration (if a natural feature) or construction (if a nature-based feature)

- Efforts to restore shoals where they may have been impacted by human activity can take the form of sediment placement or by-passing at inlets. Through by-passing sediment collected on the updrift side of a maintained inlet can be mechanically placed to emulate a flood or ebb shoal, an offshore bar, or to restore a downdrift beach. See the beach feature description for more information on by-passing.
- Consult with the appropriate regional agencies before beginning any in-water project.

Sources

1. Bridgham, S., Megonigal, J., Keller, J., Bliss, N., & Trettin, C. (2006). The Carbon Balance of North American Wetlands. Wetlands, 26(4): 889–916. Retrieved from *ftp://131.252.97.79/Transfer/WetlandsES/Articles/es/bridgham_06_wetlandES_carbonsequest.pdf*

2. Federal Geographic Data Committee (FGDC). (2012). Coastal and Marine Ecological Classification Standard (FGDC-STD-018-2012). Retrieved from *https://www.fgdc.gov/standards/projects/cmecs-folder/CMECS_Version_06-2012_FINAL.pdf*

3. FitzGerald, D. M. (1988*).* Shoreline Erosional-Depositional Processes Associated with Tidal Inlets. In: Hydrodynamics and Sediment Dynamics of Tidal Inlets (pp. 186–225). New York, NY: Springer Science + Business Media.

4. Kennett, J. P. (1982). Marine Geology. Englewood Cliffs, NJ: Prentice-Hall.

5. Leatherman, S. P. (1979). Barrier Island Handbook. Amherst, MA: National Park Service, Cooperative Research Unit, The Environmental Institute, University of Massachusetts at Amherst.

6. New York Power Authority (NYPA). (2010). Frog Island Design Report Draft. White Plains, NY: NYPA. Retrieved from *http://niagara.nypa.gov/EcologicalStandingCommittee/FrogIslandDesignCompendiumDraft.pdf*

7. Pendleton, L., Donato, D. C., Murray, B. C., Crooks, S., Jenkins, W. A., Sifleet, S., Craft, C., Fourqurean, J. W., Kauffman, J. B., Marbà, N., Megonigal, P., Pidgeon, E., Herr, D., Gordon, D., Baldera, A. (2012). Estimating Global ''Blue Carbon'' Emissions from Conversion and Degradation of Vegetated Coastal Ecosystems. PLoS ONE, 7(9): e43542. doi: *10.1371/journal.pone.0043542*

8. Schwab, W. C., Baldwin, W. E., Denny, J. F., Hapke, C. J., Gayes, P.T., List, J. H., Warner, J. C. (2014). Modification of the Quaternary Stratigraphic Framework of the Inner-Continental Shelf by Holocene Marine Transgression: An Example Offshore of Fire Island, New York. Marine Geology, 355: pp. 346–360.

9. Sustain Our Great Lakes (SOGL). (2017). Lake Herring and Lake Whitefish Spawning Shoal Restoration in Lake Ontario. Retrieved from *http://www.sustainourgreatlakes.org/projects/lake-herring-and-lake-whitefish-spawning-shoal-restoration-in-lake-ontario/*

10. U.S. Army Corps of Engineers (USACE). (2002). Coastal Morphodynamics. In: USACE Coastal Engineering Manual (EM 1110-2-1100 Part IV) (pp. 3–26). Retrieved from *http://www.publications.usace.army.mil/LinkClick.aspx?fileticket=MeJoIhP0JEo%3d&tabid=16439&portalid=76&mid=43544*

11. U.S. Army Corps of Engineers (USACE). (2009). FIMP: Fire Island Inlet to Montauk Point Reformulation Study, Draft Formulation Report. Draft Formulation Report. New York District.

12. U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). (2013). Glossary of Landform and Geologic Terms. In: National Soil Survey Handbook Part 629*.* Retrieved from *https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_054230*

A.15 – Stream

What is a stream?

A stream or river is a natural waterway with a detectable current, having defined bed and banks, with perennial, intermittent or ephemeral flow (Figure A.15-1). Streams and rivers drain water from the land within a watershed. The bed is the bottom of a stream or river. The bank is the side of the stream or river, making up the land area immediately adjacent to, and which slopes toward, the bed, and which is necessary to maintain its structure and integrity. Natural meanders are curves in the stream that slow down the water and reduce the energy that could cause erosion.

The character of a stream is influenced by the amount of water it carries, the geology and soil types that it flows through and the shape, slope and land cover of its valley. Stream corridors, or streamways, are areas where the stream is likely to move laterally across the landscape. The stream corridor includes the stream, banks, meanders, floodplain and riparian areas. During flooding, streams can move within their streamway suddenly and significantly due to sediment erosion and deposition (Figure A.15-2). *For this reason, structures or assets sited within or near streams are considered to be at greater risk.*

Streams are influenced by the cumulative effects of land cover, land use and activities in the watershed. A healthy stream or river maintains water flows and sediment loads in a state of balance. A balanced healthy stream can transport water and sediment and dissipate the water's energy while maintaining its shape over time without excessive erosion or deposition of sediment. As inputs of water or sediment change, streams naturally change in response. A healthy stream often has minimal disturbance in its watershed (e.g. <10% of paved or impervious surfaces), is connected to the floodplain during high flows (high velocity), its riparian zone is well-vegetated, and its channel is not confined from meandering. As a result, waterway movement (meander migration) and streambed and streambank erosion are minimal.

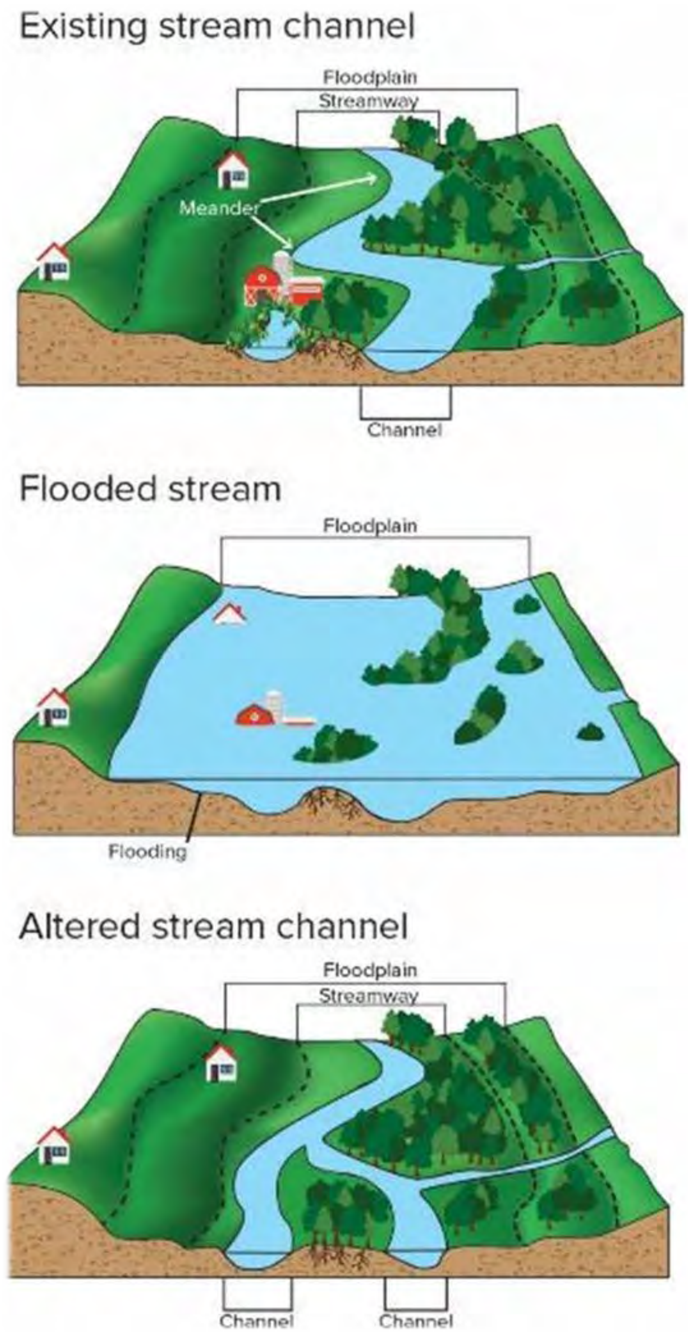
New York State regulates the bed and banks of streams. An Article 15 Protection of Waters Permit is required from NYS DEC where there is a disturbance in navigable waters or to certain streams.[31] [32]

[31] Use and Protection of Waters 6 NYCRR Part 608, 1994, *http://www.dec.ny.gov/permits/6554.html*

[32] To determine if a permit is required for a project at a specific location contact the Division of Environmental Permits in the appropriate DEC Regional Office.

Credit: NYS DEC.

Figure A.15-1. A natural stream in a healthy forest that includes diverse types and sizes of native vegetation.



Credit: NYS DEC.

Figure A.15-2. This set of illustrations show the stream channel, floodplain, meander and streamway and how they can change during a flood.
The middle diagram illustrates how water fills the floodplain during a flood. In flood conditions, the stream can move within the streamway and damage structures sited too close to the stream. The bottom diagram illustrates how the stream channel can split and moved as a result of the flood.

How do streams reduce risk?

Streams are typically part of a larger natural system which includes floodplains, riparian areas, banks, wetlands and forests. Conserving this larger natural system reduces risk near streams and in the floodplain. Risk reduction will vary based on management of these individual features. Other measures may be needed to further reduce risk from large surge or flood events.

Streams reduce risk by providing the following characteristics:

- **Reduce energy:** Friction and roughness in stream bed and banks and vegetation can dissipate current and reduce stream velocity (Chemung County SWCD, 2006, p. 32).
- **Stabilize sediment:** The root systems of vegetation in the stream and on the banks help stabilize sediment.
- **Supply sediment:** Natural bank erosion moves sediment through the system. This is necessary to maintain a healthy balanced stream and supports the building of various features of the stream such as gravel and sand bars, beaches and vegetated shallows.
- **Convey or drain water:** Streams and rivers provide drainage pathways within the floodplain and convey water downstream. Streams alone only mitigate the risk from flooding (elevation and extent) until the bank full stage, the flow at which water first overtops the banks onto the floodplain.

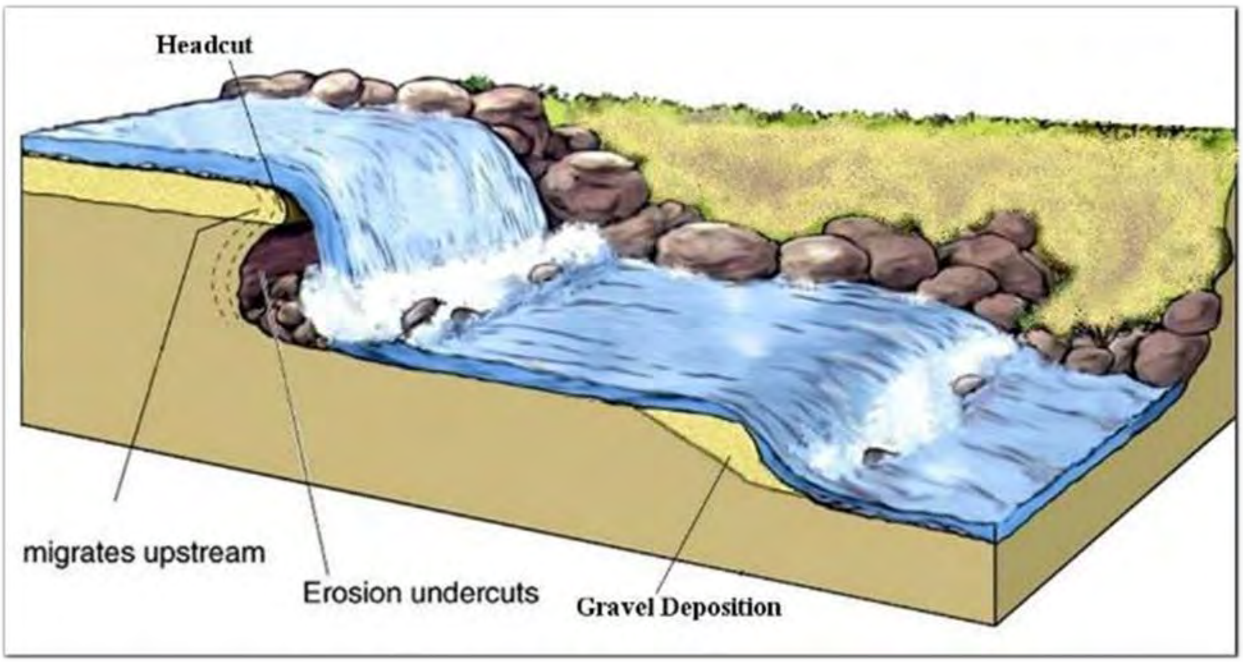
Forces and conditions that streams can mitigate to reduce risks to human assets

- Currents generally parallel to the shoreline causing damage from erosion, floating debris or the mobilization of ice
- Waves, wakes and surges generally perpendicular to the shoreline causing damage from erosion, floating debris or the mobilization of ice
- Temporarily elevated water levels from surge, high river flows or high lake levels inland of the shoreline causing property damage

Human activities that reduce or impair risk-reduction capacity

- Stream channelization, dams, berms, roads and other infrastructure built close to existing waterways can limit natural stream migration and disconnect the stream or river from the riparian area and floodplain, limiting the ability of these areas to slow and absorb water and increasing channel and bank erosion.
- Excavation or dredging of the bed may result in:
  - the loss of bed and bank materials and vegetation that provide channel roughness and dissipate energy,

- the loss of connection to the floodplain and its capacity to dissipate energy during high flows,
- altered streambed slopes which impact the velocity of the water and the amount of sediment the stream can carry
- an abrupt vertical drop (downcut or headcut) in the bed of the stream, which often migrates upstream of the excavation site (Figure A.15-3). Headcuts generate sediment. Wherever the stream deposits all of this extra sediment, it's likely to cause new problems as the shape of the channel adjusts to the new conditions.
- loss of low flow channel, which results in the stream spreading out over a wider area, losing its ability to convey sediment and resulting in increased deposition (Chemung County SWCD, 2006, pp. 31–33).



Credit: Delaware County SWCD.

Figure A.15-3. The development of a headcut or downcut in a stream.
A headcut can migrate upstream increasing erosion and sediment loads and deposit sediment further downstream.

- Removal of woody debris within a bed may result in acceleration of stream velocities and flow and erosion of the bed and bank. Woody debris should only be removed when it is causing localized scour or placing bridges and other infrastructure at risk (Chemung County SWCD, 2006).
- Efforts to control streams that rely on hard structural measures, such as armoring, hardening and straightening or resurfacing with concrete, do not allow for stream

channel adjustment. This can result in loss of vegetation in adjacent areas and design failure as a consequence of increasing water energy, volume and sediment transport. This will cause problems downstream. Similarly, creating over-sized channels can create depositional zones that can result in out-of-channel flooding. (Chemung County SWCD, 2006)

- Dams and underground piping of streams can reduce or impair risk reduction capacity by releasing water into a stream that is carrying less sediment than the stream system can handle. This "sediment starved" water has excess energy that will be used to pick up and move materials, often resulting in a deeper and/or wider channel below the dam or pipe. Dams also trap sediment supplies preventing nourishment of natural features, like wetlands, downstream. Dams can present a host of other risks associated with failure.
- Loss of instream vegetation reduces overall bank stability provided by root systems, bed friction and roughness and increases flow energy (Chemung County SWCD, 2006, p. 39).
- Alterations of bank elevation can disconnect the channel from its floodplain. If the bank is made too high, it increases water energy and erosion. If the bank is made too low, it can increase deposition in the area and cause flows outside the channel, if water engages the floodplain too easily (Chemung County SWCD, 2006).
- Land use changes in the watershed that increase stormwater (e.g. an increase in impervious or paved surfaces) can increase run-off and cause erosion of the bank. (Chemung County SWCD, 2006, p. 39; Ehrhart, 2003) because precipitation does not soak into ground and, instead, flows rapidly to stream. This can increase the frequency and magnitude of storm flows dramatically (Leopold, 1994; Hollis, 1975; NYS DEC, 2015)
- Adjacent land uses (agriculture, construction activities, etc.) and bank modification (e.g. penetration by structures, utilities or infrastructure, excavation) may result in excess sediment being introduced into the watercourse (Figure A.15-4).
- Direct discharge from outfall pipes and road ditches into streams can increase bank instability and erosion. (NYS DEC, 2015)

Credit: NYS DOS.

Figure A.15-4. The siting of this structure in a stream bed and bank is putting the structure at risk and impairing the natural ability of the stream and bank to slow water and stabilize sediment, increasing risk to downstream areas.

Other benefits

Streams provide a range of other benefits, including the following:

- **Economic:** Stable streams and rivers can support navigation and recreational opportunities like fishing, boating, wildlife viewing and swimming.
- **Habitat:** Streams provide spawning habitat for numerous fish species including trout and walleye. Stream beds are potential habitat for macroinvertebrate species like stoneflies, caddisflies and mayflies. Banks can provide important habitat for fish and wildlife.
- **Extreme heat mitigation:** Vegetated banks shade streams and reduce water temperature.

- **Community, culture and recreation:** Communities value streams for scenery and providing access for boating, fishing, swimming, hiking, hunting, trapping and bird watching. Streams are also closely coupled with some communities' sense of place and local cultural traditions.

- **Water filtration/quality:** As a stream follows its natural bed features, sediment and other impurities are dropped out in slower moving pools and glides. The tumbling effect of water over the bed substrate also helps to oxygenate the stream. Vegetated banks may filter runoff and provide water quality benefits.

- **Carbon sequestration:** Vegetated streams sequester carbon.

Possible effects of changes in climate and water levels on streams

Stronger storms

- Stronger storms coupled with large (>10%) increases in paved (impervious) areas in a watershed results in high energy flows, scouring and loss of vegetation. This reduces bank integrity and function. The stream will move and adjust until it is stable and vegetation is re-established. Development within the stream corridor, or streamway, is likely to be at greater risk as the stream responds to these changes.

Short-term drought

- Extended periods of drought may cause stream vegetation to die, reducing root and vegetation stabilization of the bank and leading to colonization by invasive species like Japanese knotweed which don't hold soil as well as native stream plants, such as willow. Well-vegetated banks with deep root systems can reduce this risk.

Restored or nature-based stream

Restored stream or river: Stream restoration is intended to restore natural stream balance and function and support a more stable condition that accommodates high flows, sediment transport, stabilizes excessive erosion or channel migration and provides habitat. Streams can be restored by conserving streamway areas, restoring a stream's access to the floodplain, revegetating the riparian area, removing dams and right-sizing culverts.

Nature-based stream or river: A nature-based approach could incorporate stream channel reconstruction, natural channel design, vegetated bank stabilization or green stormwater infrastructure to manage excessive stormwater running into a stream (Figure A.15-5). For more information, see feature descriptions for nature-based stream and constructed stormwater green infrastructure.

Credit: NYS DOS and Oneida County SWCD.

Figure A.15-5. In this stream restoration project on Sauquoit Creek, Oneida County, a stone cross-vane was installed to direct flow toward the center of the steam and the bank was stabilized with toe wood over-planted with native vegetation including live-stakes.

Examples of locations where restored or nature-based streams have been implemented

- Hudson Valley, NY: Stream barriers, primarily dams and culverts are being mapped in the Hudson Valley by the DEC Hudson River Estuary Program in partnership with municipalities, watershed groups, Cornell University and Cornell Cooperative Extension. Some dams have been removed and several culverts have been improved to restore free flowing streams and improve passage for fish and other aquatic life. *http://www.dec.ny.gov/lands/99489.html*.
- New York: DEC's "Trees for Tribs" Program is actively replanting riparian areas in targeted high risk areas and reduce erosion and improve habitat around the state. *www.dec.ny.gov/animals/77710.html*.
- Catskills, NY: The Catskill Stream Buffer Initiative provides information and assistance to landowners in the watershed of the New York City drinking water reservoirs to promote stewardship of their riparian areas through protection, enhancement, management or restoration of streams. *http://catskillstreams.org/catskill-streams-buffer-initiative/*.

- Yonkers, NY: This stream daylighting project has daylighted a stream covered for decades by urban development. http://daylightyonkers.com/.
- Vermont: Vermont has shown risk reduction benefits from using conservation easements to protect and preserve riparian areas and stream corridors. (Kline, 2008).

Factors to consider in design, construction and maintenance for restoration (if a natural feature) or construction (if a nature-based feature)

- Streams are classified by stream type based on their characteristics. It is critically important to understand and classify a stream before a project begins to identify appropriate measures.
- Restored and nature-based stream projects should aim to maintain adequate room for the stream to move laterally in its streamway. Connections to riparian areas and floodplains are essential to maintaining stream health.
- If a hard structural feature fails on a stream, consider restoring natural stream conditions or using nature-based features that mimic natural conditions and processes. Vegetation should be maintained and replanted as needed to maintain stable banks.

Resources

- United States Geological Survey (USGS) Future Flow Explorer can be used to estimate future flows under climate change: https://ny.water.usgs.gov/maps/floodfreq-climate/ or search for FutureFlow Explorer at https://www.nyclimatescience.org/
- The Natural Resource Navigator, developed by the Nature Conservancy and partners, identifies streams and their vulnerability to climate change, as well as recommended actions to address vulnerabilities in New York State: http://maps.naturalresourcenavigator.org/#
- Consult the appropriate regulatory agencies before beginning any project in the bed or on the banks of a stream or river.

Sources

1. Ashokan Streams. (2013). Diagram of Floodplain. Floodplain Management. Retrieved from http://ashokanstreams.org/our-areas-of-focus/floodplain-management/

2. Baldigo, B. P., Ernst, A. S., Keller, W., Warren, D. R., Miller, S. J., Davis, D., Baudanza, T.P. DeKoskie, D., & Buchanan, J. R. (2006). Restoring Geomorphic Stability and Biodiversity in Streams of the Catskill Mountains (p. 587–600). New York: American Fisheries Society Symposium, American Fisheries Society.

3. Chemung County Soil & Water Conservation District (SWCD). (2006). Stream Processes: A Guide to Living in Harmony with Streams. Retrieved from *http://www.catskillstreams.org/pdfs/chemungstreamguide.pdf*

4. Ehrhart, B. (2003). Riparian Areas. Functions and Strategies for Management. Washington, D.C., USA: National Academy Press. Environmental Conservation, 30(04): 408–409.

5. Federal Interagency Stream Restoration Working Group (FISRWG). (1998). Stream Corridor Restoration: Principles, Processes and Practices. Retrieved from *http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044574.pdf*

6. Florsheim, J. L., Mount, J. F., & Chin, A. (2009). Bank Erosion as a Desirable Attribute of Rivers. BioScience 58 (6): 519–529. doi: 10.1641/B580608.

7. Friends of the Winooski River. (2012). Living in Harmony with Streams. A Citizens Handbook to How Streams Work.

8. Goudie, A. S. (2004). Encyclopedia of Geomorphology. New York, NY: Routledge.

9. Hollis, G. E. (1975). The Effect of Urbanization on Floods of Different Recurrence Interval. Water Resources Research, 11(3): 431–435. Retrieved from doi: 10.1029/WR011i003p00431.10.1029/WR011i003p00431

10. Kline, M. (2008). A Guide to River Corridor Easements. River Management Program, Vermont Agency of Natural Resources, Department of Environmental Conservation. Retrieved from *http://www.watershedmanagement.vt.gov/rivers/docs/rv_RiverCorridorEasementGuide.pdf*

11. Leopold, L. B. (1994). A View of the River. Cambridge, MA: Harvard University Press.

12. New York Environmental Conservation Law § 15-0501. Water Resources—Protection of Water: Protection of Certain streams; Disturbances of Stream beds.

13. New York Environmental Conservation Law § 15-0505. Water Resources—Protection of Water: Protection of Navigable waters; Excavation or Fill.

14. New York Environmental Conservation Law § ARTICLE 15 TITLE 27: Wild Scenic and Recreational Rivers Act.

15. New York Invasive Species Information. (2016). Japanese Knotweed. Retrieved from *http://www.nyis.info/*

16. New York State Department of Environmental Conservation (NYS DEC) Bureau of Habitat. (2006). Shoreline Protection Interpretive Guidance to Staff: Aquatic Habitat Protection Program. Retrieved from *http://www.dec.ny.gov/permits/6042.html*

17. New York State Department of Environmental Conservation (NYS DEC). (2015). New York State Stormwater Management Design Manual. Retrieved from http://www.dec.ny.gov/docs/water_pdf/swdm2015entire.pdf

18. New York State Department of Environmental Conservation (NYS DEC). Storm Water Management. (n.d.). Retrieved from http://www.dec.ny.gov/chemical/8468.html

19. Title 6 of the New York Codes, Rules and Regulations (NYCRR). (1994). Part 608: Use and Protection of Waters. NYS DEC Shoreline Stabilization. Retrieved from http://www.dec.ny.gov/permits/50534.html

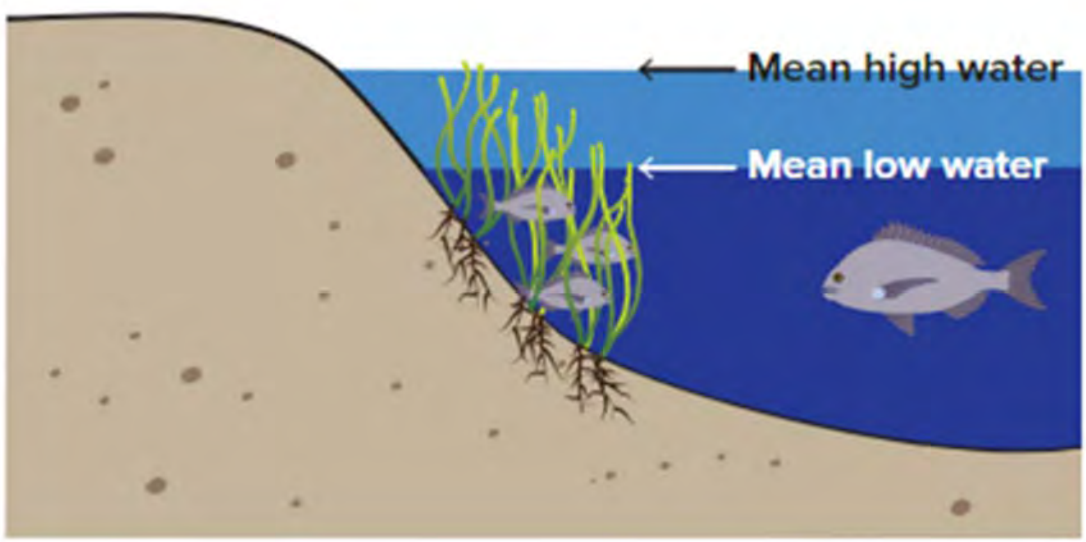
20. U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). (2007). Part 654 Stream Restoration Design National Engineering Handbook. Report No. 210–VI–NEH. Retrieved from http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/water/manage/restoration/?cid=stelprdb1044707 p. xix to xlv.

21. U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). (1996). Part 650 Engineering Field Handbook, Chapter 16 Streambank and Shoreline Protection. Retrieved from http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17553.wba.

A.16 – Submerged Aquatic Vegetation (SAV)

What is Submerged Aquatic Vegetation?

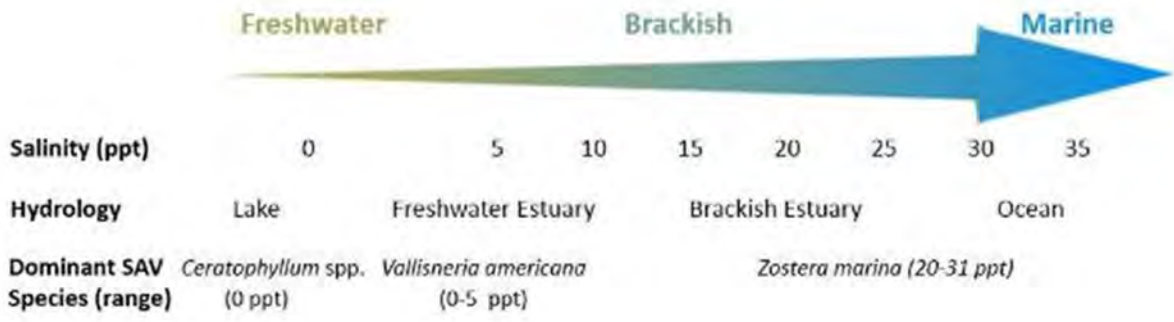
Submerged aquatic vegetation (SAV) are rooted, vascular, flowering plants that, except for some flowering structures, live and grow below the water surface where light can reach them (Figure A.16-1). SAV beds reduce risk by reducing water velocity and stabilizing sediment.



Credit: NYS DEC.

Figure A.16-1. Submerged aquatic vegetation grows in depths where sunlight can penetrate, which is dependent on water clarity.

Figure A.16-2 depicts the types of waterbodies, salinities and common species of SAV. In saline environments, SAV include true seagrass species such as eelgrass (*Zostera marina*) (Figure A.16-3) and widgeon grass (*Ruppia maritima*) (NYS DEC, 2009). In the freshwater Hudson River Estuary common species are *Vallisneria americana* (water celery) (Figure A.16-4), the invasive species *Potamogeton crispus* (pondweed), *Myriophyllum spicatum* (Eurasian water milfoil) and water chestnut (*Trapa natans*) (Findlay et al., 2006a). In freshwater lakes, ponds and streams common plants include coontail (*Ceratophyllum spp*.), milfoils and pondweeds (Figure A.16-5). *Cladophora* is a native, filamentous, green alga that grows attached to solid substrate in all of the Laurentian Great Lakes. It is increasing in extent due to increases in water clarity due to invasive zebra and quagga mussel water filtration.



Credit: NYS DEC.

Figure A.16-2. Dominant SAV species in New York State (*Ceratophyllaceae* or coontail, *Vallisneria americana* or water celery and *Zostera marina* or eelgrass) and the salinities necessary to support their survival.

In marine areas, sediment characteristics, salinity, water quality (especially clarity), temperature and presence of aquatic animals are all key to sustaining SAV. Wave climate is an additional important factor in seagrass distribution. In the freshwater tidal waters of the Hudson River, SAV location, plant size, density and plant community type are controlled primarily by water clarity and exposure to wind and waves (Findlay et al., 2006b). SAV presence varies along Great Lakes shorelines with ambient phosphorus levels, local nutrient sources, mussel density, water clarity, bottom substrate and topography.

SAV can move or change significantly as energy and water from strong storms or other sources are absorbed. The distribution of SAV is highly dynamic so that absence in any particular year does not preclude future appearance of submerged plants at that location (Findlay et al., 2014).

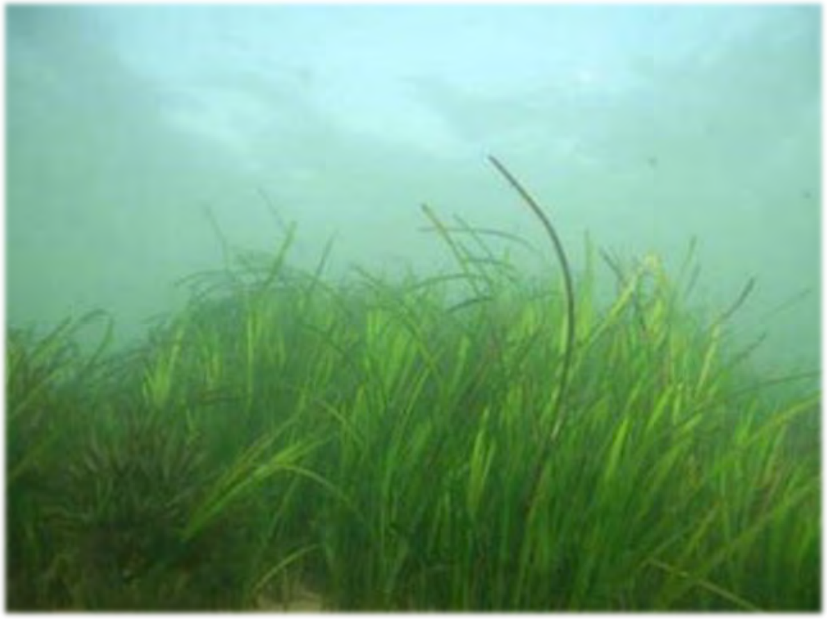


Figure A.16-3. Eelgrass (Zostera marina). Photo credit: Cornell University Cooperative Extension of Suffolk County (n.d.) Marine Program.

Credit: NYS DEC.

Figure A.16-4. Water celery (*Vallisneria americana*).

Credit: USDA-NRCS PLANTS Database, Mohlenbrock (1995).

Figure A.16-5. Pondweed (*Ceratophyllum*) a freshwater type of SAV.

How does SAV reduce risk?

SAV is typically part of a larger coastal or riverine system which may include beaches, shoals, nearshore areas, tidal wetlands, floodplains and banks. Conserving this larger natural system reduces risk in shoreline areas. Risk reduction will vary based on management of these individual features. Other measures may be needed to further reduce risk from large surge or flood events.

SAV provides the following risk reduction benefits:

- **Reduces water velocity:** Submerged aquatic vegetation beds dampen wave height and absorb wave energy through friction from the movement of water over the plants' stems and leaves during the growing season. The dampening capacity is a function of the size and density of plants, shoreline characteristics and individual storm characteristics. The height of vegetation reduces water depth available to support incoming waves therefore reducing wave height (Smith and Anderson, 2014) the dampening of waves and reduction of wave height helps to minimize shoreline erosion. The dampening of waves and reduction of wave height helps to minimize shoreline erosion.

- **Stabilizes sediment:** SAV roots and rhizome mats can also reduce erosion risk by holding sediment in place and stabilizing soft bottom sediments. Under the right conditions, SAV slows water and enables sediment to accumulate (Ward et al., 1984).

Forces and conditions that SAV can mitigate to reduce risks to people and communities

- Currents generally parallel to the shoreline causing damage from erosion, floating debris or the mobilization of ice[33]
- Waves, wakes and surges generally perpendicular to the shoreline causing damage from erosion, floating debris or the mobilization of ice

Human activities that reduce or impair risk-reduction capacity

- Nutrient and sediment inputs from stormwater runoff over developed or fertilized land, such as lawns and golf courses, and into groundwater, especially from septic systems, can lead to algae blooms and increased sedimentation, both of which degrade the water clarity needed for vegetation growth.
- Toxic chemicals in runoff from urbanized and agricultural lands may kill aquatic plants or other aquatic life. Herbicides, in particular, are known to adversely impact seagrasses.
- Structures over the water can affect light availability needed for proper growth of SAV.
- Boat wakes, propeller or keel disturbance, anchor or mooring scour, certain fishing practices, wave and current reflection from hardened shorelines and excavation and dredging can all cause disturbances that erode or rip out submerged aquatic vegetation or cause sedimentation that smothers the vegetation.

Other benefits

SAV provides a range of other benefits, including the following:

- **Economic:** Native SAV beds provide critical habitat that support commercial and recreational fisheries and benefits ecotourism. SAV provides erosion control and improve water clarity: improving aesthetics and providing economic benefits (Sea Grant, 2001).

- **Habitat:** Crabs, scallops, numerous species of fish and other commercially and ecologically important wildlife live or forage in marine seagrass beds. The blades of the grasses are often covered with other marine algae and animals. SAV are an important component of Great Lakes coastal wetland habitats. (Grimm et al., 2015). Like trees in a forest, aquatic plants provide structure and food for other organisms. A healthy plant

[33] SAV stems and leaves are only present during the growing season.

community in a lake also makes the lake less susceptible to the spread of exotic plants like Eurasian water milfoil.

- **Community, culture and recreation:** SAV can improve water clarity, improving beach aesthetics and provide habitat and recreational benefits for birding and fishing.
- **Carbon sequestration:** Seagrass beds can be extremely effective at sequestering carbon dioxide (McLeod et al., 2011; NOAA Fisheries, 2017). Methods of quantifying net greenhouse gas emission reductions and removals that result from seagrass restoration projects can be found at: *http://verra.org/methodology/vm0033-methodology-for-tidal-wetland-and-seagrass-restoration-v1-0/*

Possible effects of changes in climate and water levels on tidal wetlands

Sea-level rise/water level change

- In tidal areas, SAV beds will drown as sea levels rise if they are bounded by developed banks or steep slopes. Conservation of land areas for shoreward migration is needed to ensure these features can migrate inland as water levels rise.
- In the Great Lakes, fluctuations in water levels will affect the distribution of SAV as water depth and clarity affect the ability of sunlight to reach SAV beds (Zhu et al., 2007). SAV will colonize shoreward if lake levels are deeper for a growing season and colonize further away from shore if lake levels become shallower.

Stronger storms

- Strong storms cause upland erosion. This excess sediment is carried into waterbodies and deposited, which can bury SAV and cause temporary die outs.
- Stronger storms may cause longer periods of turbidity, reducing water clarity and SAV access to sunlight. After Hurricane Irene and Lee in 2011, substantial reductions in SAV were observed in the Hudson River. It has gradually recovered. In 2017, volunteer monitoring data showed that the SAV had recovered to approximately 2/3 of its pre-storm areal extent.
- Storms can uproot and/or bury aquatic plants, especially in smaller SAV beds that lack substantial rhizome mats.

Warmer temperatures

- Warmer temperatures will stress some native seagrass species, such as *Zostera* spp., and may reduce their survival. Southern seagrass species may outcompete native seagrass species in New York. While, southern species are more tolerant to warmer temperatures, they have less structure and size and do less to dampen waves and erosion. They may also be associated with less aquatic animal diversity.

Restored or nature-based SAV

- **Restored Natural SAV:** SAV beds can be protected and enhanced by minimizing sources of disturbance to SAV beds and improving water quality (clarity) by reducing nutrient loading and pollution. Restoration can be accomplished by removing aquatic invasive species and /or replanting native species of aquatic vegetation.
- **Nature-based SAV:** Submerged aquatic plants could be planted to create new SAV beds in conjunction with nature-based coastal techniques depending on site conditions.

Examples of locations where restored or nature-based SAV has been implemented

- Long Island: SAV has been restored in several locations *http://www.seagrassli.org/restoration/current_projects.html*
- Chesapeake Bay: SAV has been restored in several locations *http://chesapeakebay.noaa.gov/submerged-aquatic-vegetation/protecting-and-restoring-submerged-aquatic-vegetation*
- Hudson River: Experiments in SAV restoration have been attempted in the Hudson River (Hamberg et al., 2015, 2016; S. Findlay and C. Bowser, personal communication.)
- Unity Island, near Buffalo, NY: A demonstration project is underway to control invasive and restore native SAV, using plantings and hydrological control mechanisms *http://www.lrb.usace.army.mil/Media/News-Releases/Article/622242/usace-awards-contract-for-unity-island-aquatic-and-riparian-invasive-species-ma/*

Factors to consider in design, construction and maintenance for restoration (if a natural feature) or construction (if a nature-based feature)

- Protect seedlings to enhance restoration success. While water quality is important for SAV growth and survival, the success of SAV restoration has been found to be most limited by grazing on initial recruits (Moore et al., 2010). However, communities of fishes, epifaunal invertebrates and aquatic mammals which utilize SAV beds as critical habitat and/or exert biological controls on grazing of SAV beds by other species may also be important to sustain the feature.
- Enhance connectivity and expansion of SAV beds by focusing restoration efforts in areas they are likely to migrate to in response to climate change impacts.
- Manage stormwater, non-point source nutrient inputs, thermal pollution from power plants and other sources and other threats that affect water quality and the survivability of native SAV (NYS DEC, 2009).
- Improve water clarity: Water clarity can have a significant influence on SAV. (EPA, n.d.)

Resources

- NYS DEC drafted guidance (2005) on the management of freshwater aquatic plants, including management of invasive SAV and restoration of native SAV is available. *http://www.dec.ny.gov/animals/7137.html*
- Suitability indices, models and methods have been developed to aid in identifying appropriate restoration criteria.
- CCE of Suffolk County: Seagrass.LI. Methods of Restoring Eelgrass. *http://www.seagrassli.org/restoration/methods.html*
- Vaudrey et al. (2013). *http://digitalcommons.uconn.edu/marine_sci/3http://digitalcommons.uconn.edu/marine_sci/3*
- Pickerell et al. (2009). *http://www.seagrassli.org/restoration/projects/sse/Southampton%20Eelgrass%20and%20Bay%20Scallop%20Restoration%20Planning%20Project-%20Final%20Report.pdfhttp://www.seagrassli.org/restoration/projects/sse/Southampton%20Eelgrass%20and%20Bay%20Scallop%20Restoration%20Planning%20Project-%20Final%20Report.pdf*
- The Hudson River National Estuarine Research Reserve (HRNERR) held an SAV Restoration Workshop in 2014. A decision tree was developed that lists considerations for determining if SAV beds were stable, recovering, requiring maintenance or in need of restoration actions. *https://www.hrnerr.org/estuary-training/trainingtopic/sav-restoration-workshop/*
- In the Great Lakes, *Cladophora* and other SAV in Lakes Michigan, Huron, Erie and Ontario were mapped using satellite imagery by Michigan Tech Research Institute. *http://www.mtri.org/cladophora.html*
- Maps were generated to document the coverage of native SAV and invasive *Trapa natans* within the Hudson River Estuary from Troy to Hastings-on-Hudson in 1997, 2002, 2007 and 2014. Hudson River Estuary Submerged Aquatic Vegetation maps are available at the *NYS GIS Clearinghouse*.
- The US Army Corps of Engineers completed a characterization of SAV beds as part of the Fire Island to Montauk Point study on the Atlantic Coast of Long Island. *http://www.nan.usace.army.mil/Portals/37/docs/civilworks/projects/ny/coast/fimp/FIMP2.pdf*
- The Long Island Sound Study published a technical support manual for SAV habitat restoration. *http://longislandsoundstudy.net/wp-content/uploads/2004/12/sav-with-cover1.pdf*
- Consult the appropriate regulatory agencies before beginning a project near an SAV bed or any restored or nature-based SAV project.

Sources

1. Cornell University Cooperative Extension of Suffolk County. (n.d.). Methods of Restoring Eelgrass. Cornell University Cooperative Extension of Suffolk County from SeaGrassLI.org Retrieved from http://www.seagrassli.org/restoration/methods.html

2. Findlay, S. E. G., Strayer, D .L., Smith, S.D., & and Curri, N. (2014). Magnitude and Patterns of Change in Submerged Aquatic Vegetation of the Tidal Freshwater Hudson River. Estuaries and Coasts, 37(5): 1233–1242.

3. Findlay, S. E., Nieder, W. C., Blair, E. A., & Fischer, D. T. (2006a). Multi-Scale Controls on Water Quality Effects of Submerged Aquatic Vegetation in the Tidal Freshwater Hudson River. Ecosystems, 9(1): 84–96.

4. Findlay, S. E., Strayer, D., Bain, M., & Nieder, W. C. (2006b). Ecology of Hudson River Submerged Aquatic Vegetation. Final Report to the New York State Department of Environmental Conservation. Cornell University, College of Agriculture and Life Sciences and the New York State Department of Environmental Conservation's Hudson River Estuary Program.

5. Grimm, A., Schuchman, R. A., & Brooks, C. N. (2015). Mapping Submerged Aquatic Vegetation in the Great Lakes Using Satellite Imagery. Michigan Tech Research Institute.

6. Hamberg, J., Limburg, K. E., Findlay, S. E. G., & S. Diemont. (2015). Factors for Loss and Restoration of *Vallisneria americana* in the Hudson River—Herbivory and Depth in Sediment (Section V, pp. 1–22). In: S.H. Fernald, D.J. Yozzo and H. Andreyko (Eds.), Final Reports of the Tibor T. Polgar Fellowship Program, 2014. Hudson River Foundation.

7. Hamberg, L. J., Findlay, S., Limburg, K., & Diemont, S. (2016). Post-Storm Sediment Burial and Herbivory of *Vallisneria americana* in the Hudson River Estuary: Mechanisms of Loss and Implications for Restoration. Restoration Ecology.

8. McLeod, E., Chmura, G. L., Bouillon, S., Salm, R., Björk, M., Duarte, C. M., Lovelock, C. E., Schlesinger, W. H., & Silliman, B. R. (2011). A Blueprint for Blue carbon: Toward an Improved Understanding of the Role of Vegetated Coastal Habitats in Sequestering CO2. Frontiers in Ecology and Environment, 9(10): 552–560.

9. Mohlenbrock, R. H. (1995). Northeast Wetland Flora: Field Office Guide to Plant Species. Northeast National Technical Center, Chester. Hosted by the USDA NRCS PLANTS Database. Retrieved from https://plants.usda.gov/core/profile?symbol=CEDE4https://plants.usda.gov/core/profile?symbol=CEDE4

10. Moore, K. A., Shields, E. C., & Jarvis, J.C. (2010). The Role of Habitat and Herbivory on the Restoration of Tidal Freshwater Submerged Aquatic Vegetation Populations. Restoration Ecology, 18(4): 596–604.

11. National Oceanic and Atmospheric Administration (NOAA) Fisheries. (2017). Coastal Blue Carbon. Retrieved from *http://www.habitat.noaa.gov/coastalbluecarbon*

12. New York State Department of Environmental Conservation (NYS DEC). (2005). A Primer on Aquatic Plant Management in New York State: Draft. NYS DEC Division of Water. Retrieved from *http://www.dec.ny.gov/docs/water_pdf/ch6apr05.pdf*

13. New York State Department of Environmental Conservation (NYS DEC). (2009). Final Report of the New York State Seagrass Task Force: Recommendations to the New York State Governor and Legislature. Retrieved from *http://www.dec.ny.gov/docs/fish_marine_pdf/finalseagrassreport.pdf*

14. Nieder, W. C., Barnaba, E., Findlay, S. E., Hoskins, S., Holochuck, N., & Blair, E. A. (2004). Distribution and Abundance of Submerged Aquatic Vegetation and *Trapa natans* in the Hudson River Estuary. Journal of Coastal Research: 150–161.

15. Pickerell, C., Rivara, G., Petersen Manzo, K., & Schott, S. (2009). Town of Southampton Eelgrass and Bay Scallop Restoration Planning Project: Final Report. Cornel Cooperative Extension Marine Program. Retrieved from *http://www.seagrassli.org/restoration/projects/sse/Southampton%20Eelgrass%20and%20Bay%20Scallop%20Restoration%20Planning%20Project-%20Final%20Report.pdf*

16. Sea Grant. (2001). The Economic Contribution of the Sport Fishing, Commercial Fishing, and Seafood Industries to New York State (Final). Sea Grant College of State University of New York and Cornell University.

17. Sheffer, M. (1998). Ecology of Shallow Lakes. London, UK: Chapman and Hall.

18. Smith, J. M., & Anderson, M. E. (2014). Limits of Wetland Wave Dissipation, Coastal Engineering Proceedings. No. 34. Proceedings of 34th Conference on Coastal Engineering, Seoul, Korea.

19. U.S. Environmental Protection Agency (EPA). (n.d.). Indicators: Water Clarity. Retrieved from *https://www.epa.gov/national-aquatic-resource-surveys/indicators-water-clarity*

20. Vaudrey, J. M., Eddings, J., Pickerell, C. Brousseau, L., & Yarish, C. (2013). Development and Application of a GIS-based Long Island Sound Eelgrass Habitat Suitability Index Model. Department of Marine Sciences. University of Connecticut. Retrieved from *https://opencommons.uconn.edu/marine_sci/3*

21. Ward, L. G., Kemp, W. M., & Boynton, W. R. (1984). The Influence of Waves and Seagrass Communities on Suspended Particulates in an Estuarine Embayment. Marine Geology, 59(1–4): 85–103.

22. Zhu, B., Fitzgerald, D. G., Hoskins, S. B., Rudstam, L. G., Mayer, C. M., & Mills, E. L. (2007). Quantification of Historical Changes of Submerged Aquatic Vegetation Cover in

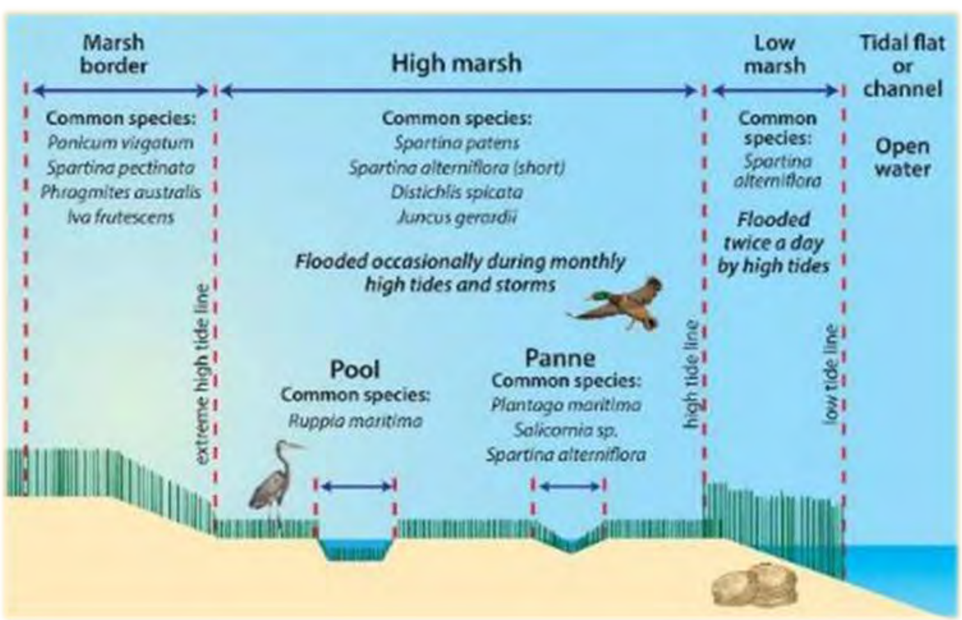
Two Bays of Lake Ontario with Three Complementary Methods. Journal of Great Lakes Research, 33(1): 122–135.

A.17 – Tidal Wetlands

What is a tidal wetland?

Tidal wetlands (or marshes) are areas that are regularly inundated or saturated by saline water or, in estuaries, freshwater, at a frequency and duration sufficient to support vegetation typically adapted for life in saturated soil conditions (Figure A.17-1). These areas can be either inundated twice daily by tides or only periodically flooded during high or "spring" tides a few times a month. Along New York's marine coastline the most typical tidal wetland types are salt marshes and mudflats or tidal flats (Figure A.17-2). Along the Hudson River estuary, tidal wetlands range from brackish to freshwater conditions (Figure A.17-3). Tidal wetlands reduce risk by reducing water velocity, absorbing water and stabilizing sediment.

The formation and function of wetlands vary by wetland type (EPA, 2001). Sediment and sedimentary characteristics, erosion/accretion rates, salinity, width, length and slope, as well as vegetation and fauna all contribute to the formation and sustainability of a wetland. The surface of a tidal wetland may increase in elevation over time as sediment and organic material is deposited by flood water. This can be augmented by the decomposition of vegetation. Maintenance of a continual, regular tidal exchange is critical to sustaining this feature. If tidal wetlands are spatially constrained, they are often more impacted by energy and water from storms or other sources.



Credit: Maine Sea Grant, K. Tenga-Gonzalez (n.d.).

Figure A.17-1. Examples of tidal marine wetland vegetation zones, with vegetation types.
Fresh-water tidal wetland zones have freshwater vegetation.

Both freshwater and marine tidal wetlands are defined in New York State primarily by their vegetation and the amount of water covering the area at high and low tide. Marine tidal wetland descriptions are found on the DEC website (*http://www.dec.ny.gov/lands/5120.html*) and delineated on Tidal Wetland Regulatory Maps for the Marine District. Freshwater tidal wetlands can be found on the Freshwater Wetland Regulatory Maps on the Environmental Resource Mapper (*http://www.dec.ny.gov/gis/erm/*). Wetlands along the Hudson River that are inundated at Mean High Water (MHW) are protected through Protection of Waters act. Any excavation or fill below MHW requires a permit from the NYS DEC.[34]

Credit: NYS DEC.

Figure A.17-2. A marine tidal wetland along the shoreline in Long Island.

[34] To determine if a permit is required for a project at a specific location contact the Division of Environmental Permits in the appropriate DEC Regional Office.

Credit: NYS DEC.

Figure A.17-3. Freshwater tidal wetland in Kingston, New York at the mouth of Rondout Creek on Hudson River.

How do tidal wetlands reduce risk?

Tidal wetlands are typically part of a larger natural system which may include maritime forests, floodplains, riparian areas, submerged aquatic vegetation, shoals and nearshore areas. Conserving this larger natural system reduces risk near tidal wetlands. Risk reduction will vary based on management of these individual features. Other measures may be needed to further reduce risk from large surge or flood events.

Tidal wetlands provide the following risk reduction benefits:

- **Reduces water velocity:** Wetland vegetation roots, rhizomes, stems and leaves slow water, absorb wave energy and reduce erosion (Gedan et al., 2011). Tidal wetlands reduce, but do not eliminate coastal flooding, as they occur at sea level and are already saturated. Tidal wetlands can reduce wave height and energy and capture waterborne debris, reducing storm impacts on human structures. Their capacity to reduce wave height and energy is a primarily a function of water elevation, the distance waves or surges pass across vegetation and vegetation attributes (e.g., plant type, height, stem density and leaf surface area). This capacity is also affected by storm and shoreline characteristics (Duarte et al., 2013).
- **Absorbs water:** Tidal wetland vegetation absorbs water and releases it through evapotranspiration. The roots, sediment and peat of a tidal wetland absorb and hold water in each daily tidal cycle.
- **Stabilizes sediment:** Wetland vegetation roots, rhizomes, stems and leaves slow water and trap sediment.

Forces and conditions that tidal wetlands can mitigate to reduce risks to people and communities

- Currents generally parallel to the shoreline causing damage from erosion, floating debris or the mobilization of ice
- Waves, wakes and surges generally perpendicular to the shoreline causing damage from erosion, floating debris or the mobilization of ice
- Precipitation or meltwater moving downhill to nearest waterbody causing erosion, temporary pooling and localized water damage
- Temporarily elevated water levels from surge, high river flows or high lake levels inland of the shoreline causing localized water damage

Human activities that reduce or impair risk-reduction capacity

- Direct physical disturbances including excavating or filling of tidal wetlands reduce wetland area and inhibit or destroy many wetland functions by removing or covering wetland soils, vegetation and biotic communities. This can inhibit the wave attenuation benefits wetlands, which are dependent on tidal wetland size and extent and wetland vegetation integrity.
- Poor water quality from stormwater and nonpoint source runoff from development may reduce the biomass of vegetation roots, interfering with the plant’s ability to withstand wave action (Turner, 2011). There has already been a documented loss of Long Island tidal wetlands due to a variety of causes including degraded water quality (*http://www.dec.ny.gov/lands/5113.html)*.

- Wave and current reflection from shoreline hardening structures and boat wakes can erode wetlands.
- Reduced light from overhanging structures, such as piers, docks and other structures can inhibit wetland vegetation growth.
- The creation or maintenance of barriers such as development (roads, berms or bulkheads) that prevent tidal wetlands from naturally migrating inland in response to changing sea level will reduce risk reduction capacity of tidal wetlands over time and threaten the survivability of the feature.
- Activities that limit the availability of sediments for wetland accretion, such as dam construction on tributaries, shoreline hardening, interference with sediment transport processes through the use of groins and jetties and preventing cross-island transport of sand through overwash on barrier islands can slow or preclude wetland vertical growth, which is needed for the wetlands to adapt to sea-level rise.
- Introduction and/or proliferation of invasive species can change tidal wetland vegetative structure and the capacity to reduce risk. For example, invasions of *Phragmites australis,* which provide thick, tall and dense vegetation structure may attenuate waves, but its rapid proliferation can be at the expense of native biodiversity. There also may be negative long-term consequences associated with dense stands of *Phragmites*. There is evidence it may elevate the marsh surface and decrease drainage, resulting in increased waterlogging and destabilization of the wetland platform (Wilson et al., 2014; Hartig et al., 2002).
- Filling, ditching and other degradation of wetlands and floodplains reduce their ability to hold flood waters and prevent erosion. Loss of wetlands can result in severe and costly flood damage in low-lying areas of a basin (Carter, 1996). More than 30% of NYS's tidal wetlands have been lost since 1974 (Cameron and Associates, 2015).
- Wetland adjacent areas provide additional storage capacity and soil stabilization. Wetlands are often compromised when their adjacent areas are cleared of native vegetation or covered by impervious or paved surfaces.

Other benefits

Tidal wetlands provide a range of other benefits, including the following:

- **Economic:** Tidal wetlands reduce the costs of storm damage. A recent report estimated tidal wetlands in the U.S. northeast reduced damages from Hurricane Sandy by $625 million (Narayan et al., 2016). Tidal wetlands are nursery areas for commercially and recreationally important finfish and shellfish and provide more services per unit area than any other ecosystem**.** Tidal wetlands also support ecotourism.

- **Habitat:** Tidal wetlands are some of the most biologically productive ecosystems on earth. They are important habitat for a wide variety of mammals, birds, turtles and other reptiles, fish and invertebrates, including shellfish, benthic fauna (animals that live in bottom sediment) and insects. Many animal species rely on these areas for foraging, breeding and cover.

- **Extreme heat mitigation:** Vegetated natural areas can mitigate extreme heat and the urban heat island effect by providing shade and/or through the cooling effect of evapotranspiration, which releases water vapor (and thus heat energy) to the atmosphere.
- **Community, culture and recreation:** Communities value tidal wetlands for scenery and providing access for boating, fishing, swimming, hiking, hunting, trapping and bird watching. Tidal wetlands are also closely coupled with some communities' sense of place and local cultural traditions.
- **Water filtration/quality:** Tidal wetlands protect water quality by trapping sediments and contaminants. Tidal wetland plants tend to remove excess nutrients from the water column, primarily through burial and microbial denitrification (Velinsky et al., 2013).
- **Carbon sequestration:** Marine wetlands are extremely effective at capturing carbon and storing it for thousands of years. They often have very high soil carbon sequestration rates and low methane emissions (Bridgham et al., 2006; Pendleton et al., 2012; Herr et al., 2015; Davis et al., 2015). In contrast, the destruction of tidal wetlands can create a major source of carbon emissions (McLeod et al., 2011).

Possible effects of changes in climate and water levels on tidal wetlands

Sea-level rise

- Rapid increase in sea level and/or insufficient sediment availability may limit wetlands' ability to maintain elevations suitable for their survival. However, tidal wetlands will continue to provide risk reduction and other wetland functions if they can adapt by building up the sediment surface through accretion and/or if they have room to migrate to higher elevations where low elevation open space and the absence of barriers makes this possible (Tabak et al, 2016).

Stronger storms

- Increased storm intensity can result in surges that can compress wetland surfaces and deposit debris. Low elevation waves can erode wetland edges and large pulses of stormwater can deposit contaminants and create unusually high turbidity.
- Large surges from strong coastal storms can deposit sediments that significantly contribute to wetland surface elevation and the ability of wetlands to maintain elevations suitable for their survival as sea levels rise (Orson et al., 1998; Carey et al., 2015).

Restored or nature-based tidal wetland

Restored Natural Tidal Wetlands: Tidal wetlands can be restored by removing barriers to tidal exchange and re-connecting formerly connected wetlands, removing invasive species, restoring adjacent areas, removing fill and fostering native plant communities. They can also be restored by augmenting the sediment supply to tidal wetlands that are drowning due to local increases in water elevation, global sea-level rise, subsidence of sediments and loss of sediment supply.

Nature-based Tidal Wetlands: A nature-based tidal wetland could incorporate components of a low-profile sill or other nature-based coastal techniques. These techniques can be used to temporarily protect a newly constructed wetland until vegetation is established and/or to enhance the wetlands efficacy as an erosion management measure.

Examples of locations where restored or nature-based tidal wetlands have been implemented

- Jamaica Bay Marsh Islands: Restoration of wetlands in the center of Jamaica Bay near NYC *http://www.nan.usace.army.mil/Missions/Civil-Works/Projects-in-New-York/Elders-Point-Jamaica-Bay-Salt-Marsh-Islands/*
- Seatuck and Wertheim National Wildlife Refuges: Restoration of degraded wetlands on Long Island that addresses tidal hydrology, surface water habitat, invasive species, shoreline stabilization and sea-level rise *https://www.fws.gov/hurricane/sandy/projects/LongIslandSaltMarsh.html*
- Gerritsen Creek and Mill Creek: Restoration of 31 acres of tidal wetland and 23 acres of rare coastal grassland in Jamaica Bay in Marine Park, NY *http://www.nan.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/487245/fact-sheet-gerritsen-creekmarine-park-ny/*
- Soundview Park, Bronx, NY: Wetland restoration on the east bank of the Bronx River *http://www.nan.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/487636/fact-sheet-soundview-park-bronx-new-york/*
- Iona Island Marsh: Removal of invasive *Phragmites australis* to restore native wetland vegetation in 10 acres of Iona Island Marsh at Bear Mountain, NY *http://www.trailsidezoo.org/conservation/iona-marsh*
- Ramshorn Marsh: Removal of invasive *Phragmites australis* to restore native wetland vegetation near Catskill, NY (Zimmerman and Shirer, 2013).

Factors to consider in design, construction and maintenance for restoration (if a natural feature) or construction (if a nature-based feature)

- The most important design factor is establishing the appropriate elevation relative to the tidal regime to support necessary low and high tidal marsh function during the tide cycle. This elevation will change over time as sea level rises (Tabak, 2016; Warren-Pinnacle Consulting, 2014).

- If the restoration project is planned for an area where a wetland has degraded over the course of time the root cause of the original degradation (such as impaired water quality and lack of sufficient natural sediment supply) should be understood and addressed.
- Monitoring restoration success and adaptive management are integral to any restoration project.
- Consult the appropriate regulatory agencies before beginning any project near an existing tidal wetland or the restoration or creation of a new tidal wetland.

Sources

1. Bridgham, S., Megonigal, J., Keller, J., Bliss, N., & Trettin, C. (2006). The Carbon Balance of North American Wetlands. Wetlands, 26(4): 889–916. Retrieved from *ftp://131.252.97.79/Transfer/WetlandsES/Articles/es/bridgham_06_wetlandES_carbonsequest.pdf*

2. Cameron Engineering and Associates. (2015). Long Island Tidal Wetlands Trends Analysis prepared for New England Interstate Water Pollution Control Commission. Retrieved from *http://www.dec.ny.gov/lands/5113.html*

3. Carey, J. C., Raposa, K.B., Wigand, C., & R. S. Warren. (2015). Contrasting Decadal-Scale Changes in Elevation and Vegetation in Two Long Island Sound Salt Marshes. Estuaries and Coasts. *doi: 10.1007/s12237-015-0059-8*.

4. Carter, V. (1996). Technical Aspects of Wetlands: Wetland Hydrology, Water Quality, and Associated Functions. National Water Summary on Wetland Resources, U.S. Geological Survey Water Supply Paper 2425.

5. Clean Water Act (33 CFR § 323.2(c)). (1977).

6. Davis, J. L., Currin, C. A., O'Brien, C., Raffenburg, C., & Davis, A. (2015). Living Shorelines: Coastal Resilience with a Blue Carbon Benefit. PloS one, 10(11): e0142595.

7. Deegan, L. A., Johnson, D. S., Warren, R. S., Peterson, B. J., Fleeger, J. W., Fagherazzzi, S., & Wollheim, W. M. (2012). Coastal Eutrophication as a Driver of Salt Marsh Loss. Nature, 490: 388–394.

8. Duarte, C. M., Losada, I. J., Hendriks, I. E., Mazarrasa, I., and Marba, N. (2013). The Role of Coastal Plant Communities for Climate Change Mitigation and Adaptation. Nature Climate Change, 3: 961–968.

9. Gedan, K. B., Kirwin, M. L., Wolanski, E., Barbier, E. B., & Silliman, B. R. (2011). The Present and Future Role of Coastal Wetland Vegetation in Protecting Shorelines: Answering Recent Challenges to the Paradigm. Climatic Change, 106: 7–29.

10. Gittman, R. K., Scyphers, S. B., Smith, C. S., Neylan, I. P., Grabowski, J. H. (2016). Ecological Consequences of Shoreline Hardening: A Meta-Analysis. Bioscience 66: 763–773.

11. Hartig, E. K., Gornitz, V., Kolker, A., Mushacke, F., & Fallon, D. (2002). Anthropogenic and Climate-Change Impacts on Salt Marshes of Jamaica Bay, New York City. Wetlands 22: 71–89.

12. Herr, D., Agardy, T., Benzaken, D., Hicks, F., Howard, J., Landis, E., Soles, A., & Vegh, T. (2015). Coastal "Blue" Carbon: A Revised Guide to Supporting Coastal Wetland Programs and Projects Using Climate Finance and Other Financial Mechanisms. Gland, Switzerland: IUCN.15

13. Interagency Workgroup on Wetland Restoration. (2003). An Introduction and User's Guide to Wetland Restoration, Creation, and Enhancement. Retrieved from *http://www.habitat.noaa.gov/pdf/pub_wetlands_restore_guide.pdf*

14. Kelin, H., Quin, C., & Wang, H. (2015). A Numerical Study of Vegetation Impact on Reducing Storm Surge by Wetlands in a Semi-Enclosed Estuary. Coastal Engineering, 95: 66–76.

15. Lapetina, A., & Sheng, Y. P. (2015). Simulating Complex Storm Surge Dynamics: Three-Dimensionality, Vegetation Effect, and Onshore Sediment Transport. JGR-Oceans, 120.

16. McLeod, E., Chmura, G. L., Bouillon, S., Salm, R., Björk, M., Duarte, C. M., Lovelock, C. E., Schlesinger, W. H., & Silliman, B. R. (2011). A Blueprint for Blue carbon: Toward an Improved Understanding of the Role of Vegetated Coastal Habitats in Sequestering CO2. Frontiers in Ecology and Environment, 9(10): 552–560.

17. Michaud, J. P. (2001). Chapter 2: The Functions and Values of Wetlands. In: At Home with Wetlands: A Landowner's Guide, Second Edition (pp. 17–21). Retrieved from *https://fortress.wa.gov/ecy/publications/documents/9031.pdf*

18. Narayan, S., Beck, M. W., Wilson, P., Thomas, C., Guerrero, A., Shepard, C., Reguero, B. G., Franco, G., Ingram, C. J., Trespalacios, D. (2016). Coastal Wetlands and Flood Damage Reduction: Using Risk Industry-based Models to Assess Natural Defenses in the Northeastern USA. London, UK: Lloyd's Tercentenary Research Foundation.

19. New York State Department of Environmental Conservation (NYS DEC). (n.d.). Tidal Wetlands Categories. Retrieved from *http://www.dec.ny.gov/lands/5120.html*

20. Niedowski, Nancy L. (2000). New York State Salt Marsh Restoration and Monitoring Guidelines. Retrieved from *http://www.dec.ny.gov/lands/5116.html* or *http://www.habitat.noaa.gov/pdf/saltmarsh1.pdf*

21. Orson, R. A., Warren, R. S., & Niering, W. A. (1998). Interpreting Sea Level Rise and Rates of Vertical Marsh Accretion in a Southern New England Tidal Salt Marsh Estuarine. Coastal and Shelf Science, 47: 419–429.

22. Pendleton, L., Donato, D. C., Murray, B. C., Crooks, S., Jenkins, W. A., Sifleet, S., Craft, C., Fourqurean, J. W., Kauffman, J. B., Marbà, N., Megonigal, P., Pidgeon, E., Herr, D., Gordon, D., Baldera, A. (2012). Estimating Global ''Blue Carbon'' Emissions from Conversion and Degradation of Vegetated Coastal Ecosystems. PLoS ONE, 7(9): e43542. doi: *10.1371/journal.pone.0043542*

23. Sheng, Y. P., Lapetina, A. J., & Ma, G. (2012). The Reduction of Storm Surge by Vegetation Canopies: Three-Dimensional Simulations, Geophysical Research Letters.

24. Tabak, N., Laba, M., & Spector, S. (2016). Simulating the Effects of Sea Level Rise on the Resilience and Migration of Tidal Wetlands along the Hudson River. PLoS ONE 11(4): e0152437.

25. Tenga-Gonzalez, K. M. (n.d.). Property Owners Guide to Erosion, Flooding, and Other Coastal Hazards. Maine Sea Grant. Retrieved from *https://www.seagrant.umaine.edu/coastal-hazards-guide*.

26. Turner, R. E. (2011). Beneath the Salt Marsh Canopy: Loss of Soil Strength with Increasing Nutrient Loads. Estuaries and Coasts, 34: 1084–1093.

27. Turner, R. E., Howes, B. L., Teal, J. M., Milan, C. S., Swenson, E. M., & Goehringer-Toner, D. D. (2009). Salt Marshes and Eutrophication: An Unsustainable Outcome. Limnology and Oceanography, 54: 1634–1642.

28. U.S. Environmental Protection Agency (EPA). (2001). Functions and Values of Wetlands. EPA 843-F-01-002c. EPA Office of Water and Office of Wetlands, Oceans and Watersheds (4502T). Retrieved from *https://www.epa.gov/sites/production/files/2016-02/documents/functionsvaluesofwetlands.pdf*

29. Velinsky, D., Quirk, T., Peihler, M., & Smyth, A. (2013). Ecosystem Services of Tidal Wetlands in Barnegat Bay: Nitrogen Removal. Patrick Center for Environmental Research, Report 13-06. Drexel University Academy of Natural Sciences.

30. Warren-Pinnacle Consulting, Inc. (2014). Application of Sea-Level Affecting Marshes Model (SLAMM) to Long Island, NY and New York City. Final Report. Prepared for NYSERDA.

31. Wilson, C. A., Hughes, B. J., FitzGerald, D. M., Hopkinson, C. S., Valentine, V., & Kolker, A. S. (2014). Saltmarsh Pool and Tidal Creek Morphodynamics: Dynamic Equilibrium of Northern Latitude Saltmarshes? Geomorphology, 213: 99–115.

32. Zimmerman, C., & Shirer, R. (2013). Trajectory of Vegetation Recovery in Five *Phragmites australis* Stands in Response to Management in a Hudson River Freshwater Tidal Wetland. Albany, NY: The Nature Conservancy in Eastern New York.

A.18 – Constructed Stormwater Green Infrastructure

What is Constructed Stormwater Green Infrastructure (CSGI)?

Constructed stormwater green infrastructure (CSGI) techniques mimic, accommodate or enhance the natural capture and infiltration of rainwater into the ground to reduce the risk of flooding and erosion to human assets in upland areas. Infiltration allows water to soak into the ground rather than running off into low-lying areas or flowing directly into streams. CSGI rely on vegetation alone or combined with grading, fill or addition or removal of structural components.

CSGI techniques generally do the following:

- Utilize natural materials and designs to achieve objectives
- Reduce stormwater runoff to minimize flooding and erosion
- Improve water quality
- Allow stormwater to be absorbed into the ground and recharge groundwater
- Reduce impacts of stormwater on stream or coastal habitat
- Allow re-use of stormwater

CSGI practices that reduce stormwater runoff identified in the NYS DEC Stormwater Management Design Manual are listed below (NYS DEC, 2015). Other CSGI practices exist. In existing literature and current practice these techniques may also be referred to as hybrid, biological, bioengineered, living, soft and green.

CSGI techniques should be considered before implementing a hard structural stormwater feature such as a pipe or concrete channel. For more information on distinctions between restored, nature-based and hard structural measures see Section 5 of the General Guidance on Natural Resilience Measures.

Examples of CSGI

Types of constructed stormwater green infrastructure techniques include, but are not limited to, the following:

- Tree planting/street tree pit
- Vegetated swale
- Bioretention

- Rain garden
- Disconnecting rooftop runoff
- Stream daylighting
- Green roofs
- Stormwater planters
- Rain barrels and cisterns
- Porous pavement
- Infiltration or recharge basins

Examples of nature-based stream techniques can be found below. Additional examples and information can be found in individual natural feature descriptions.

Tree planting/street tree pit: This technique consists of planting or conserving trees to reduce stormwater runoff, increase nutrient uptake and provide bank stabilization. Trees can be used for applications such as landscaping, stormwater management practice areas, conservation areas and erosion and sediment control. Stormwater street tree pits reduce stormwater volumes and velocities discharging from highly impervious areas through rainfall interception and evapotranspiration.

Vegetated swale: This technique uses natural drainage paths, or vegetated channels, to slow water moving over land, reduce peak discharge and provide infiltration into the soil instead of constructing underground storm sewers or concrete open channels.

Bioretention: This technique captures stormwater in a shallow depression underlain by a deep (4 feet or greater) planting bed with engineered soils. It is planted with vegetation that can tolerate both wet and dry conditions and includes an underdrain and a pretreatment area to capture sediment (Figure A.18-1). Bioretention can be designed to treat up to 5 acres of contributing drainage area.

Credit: NYS Environmental Facilities Corporation.

Figure A.18-1. Bioretention area capturing runoff from street in Syracuse, NY.

Rain garden: This technique uses a conditioned planting soil bed and planting materials in a shallow depression to store, manage and filter small volumes of stormwater runoff. Rain gardens can be designed to treat up to 1,000 square feet of contributing drainage area (Figure A.18-2).

Disconnecting rooftop runoff: This technique disconnects rooftop runoff from piped stormwater systems and directs it to designated pervious areas, ideally with vegetation, to reduce runoff volumes and rates (Figure A.18-2).

Credit: NYS EFC.

Figure A.18-2. Cistern collecting rooftop runoff and diverting it to a rain garden in Troy, NY.

Stream Daylighting: This technique uncovers previously-culverted or piped streams to restore natural habitats, better attenuate runoff by increasing water storage, promote infiltration and help reduce pollutant loads (Figure A.18-3).

Credit: NYS EFC.

Figure A.18-3. Daylighting of the Saw Mill River in Yonkers, NY.

Green roofs: This technique captures runoff with a layer of vegetation and soil installed on top of a conventional flat or sloped roof. The rooftop vegetation allows evaporation and evapotranspiration processes to reduce the volume and discharge rate of runoff entering conveyance system (Figure A.18-4).

Credit: NYS EFC.

Figure A.18-4. Green roof on at SUNY ESF.

Stormwater planters: This technique consists of small landscaped stormwater treatment devices, like large planters, that can be designed as infiltration or filtering practices.

Rain barrels and cisterns: This technique includes practices that capture and store stormwater runoff to be used for irrigation systems or filtered and reused for non-contact activities where it can infiltrate into the ground (Figure A.18-2 and Figure A.18-5).

Credit: NYS EFC.

Figure A.18-5. Rain barrel capturing rooftop runoff.

Porous pavement: This technique is an alternative to conventional paved surfaces. It is designed to infiltrate stormwater through the surface, thereby reducing stormwater runoff from a site and providing some pollutant removal in the underlying soils (Figure A.18-6).

Credit: NYS EFC.

Figure A.18-6. Porous pavement and a demonstration of infiltration in Lake George, NY.

Infiltration or recharge basins: This technique diverts stormwater into temporary storage, where it gradually infiltrates into the ground. They provide increased stormwater storage capacity, reduce flow rates into collector systems and surface waterbodies and may be combined with natural resource restoration or other floodplain restoration (Figure A.18-7). In dense urban areas large concrete basins may be sited under other structures such as parking lots.

Credit: NYS EFC.

Figure A.18-7. Constructed wetland recharge basin in Long Island, NY

How does CSGI reduce risk?

CSGI should be designed to support and mimic natural features and processes. CSGI are often small-scale practices and the scale of implementation relates to the level of risk reduction. The greatest risk reduction benefit is achieved when the larger natural watershed system is conserved or maintained. Risk reduction will vary based on management of these individual features. Other measures may be needed to further reduce risk from large surge or flood events.

Below are examples of how CSGI techniques mimic the natural risk reduction benefits of natural features:

- **Reduce water velocity:** CSGI practices reduce the amount of stormwater runoff traveling over land and entering waterbodies and slow down its speed, reducing erosion.
- **Absorb water:** CSGI practices allow water to be slowly absorbed into the ground or released by evapotranspiration, rather than quickly running off impervious surfaces and overwhelming water bodies or wastewater systems. Small-scale practices can reduce localized flooding; larger-scale stormwater management practices (which may be nature-based or hard structural features) or an interconnected system of small-scale practices can also help reduce stream and riverine flooding. Water harvesting practices like cisterns or rain barrels can store water to be reused. Some stormwater practices including constructed wetlands can be used to capture and contain flood waters for a designed amount of time to systematically release flows after a flood event. CSGI may also support recharge of groundwater supporting stream baseflows and water supplies during dry periods.
- **Stabilize sediment:** CSGI practices reduce and slow the amount of runoff entering waterbodies, reducing erosion. Root systems of vegetated CSGI practices stabilize sediment. Stormwater practices can also capture mobilized sediment.

Forces and conditions that CSGI can mitigate to reduce risks to human assets

- Overland flow (precipitation or snowmelt moving downhill to nearest waterbody) causing erosion, temporary pooling and localized property damage

Human activities that reduce or impair risk-reduction capacity

- CSGI or drainage that is inappropriate for the location or undersized for the catchment area can be overwhelmed by the volume of water it receives, even in smaller storms. CSGI that is oversized can result in loss of vegetation, if it's not planted appropriately and doesn't receive enough water.

- Lack of maintenance can result in vegetation, debris or sediment blocking necessary conveyance paths (e.g. drainage pipes, clogged pores in porous pavement, downspouts from green roofs).
- Lack of education of maintenance personnel can result in excessive mowing or removal of CSGI vegetation, eliminating the pollutant removal and water velocity reduction benefit of the plants.
- Addition of paved surfaces, ditching and loss of flood storage capacity in the CSGI drainage basin can overwhelm and destroy CSGI features.
- Heavy use of fertilizers in the drainage basin can negatively affect water quality coming out of the CSGI feature.

Other benefits

CSGI provide a range of other benefits, including the following:

- **Economic:** CSGI can reduce the cost of wastewater treatment by reducing inputs to wastewater systems that have combined sewers or illicit storm sewer connections. Green roofs can reduce heating and cooling costs by insulating structures. Large scale CSGI in urban areas can reduce summer cooling needs. (Stratus Consulting, 2009; American Rivers, 2012). CSGI can save costs by being designed to serve as both stormwater management and landscaping features.
- **Habitat:** If native plant species are used, practices can provide resources for pollinators and improve habitat, especially in urban areas. CSGI practices can reduce the negative effects of stormwater runoff on natural areas.
- **Drought mitigation:** Infiltration can help replenish ground and surface water and reduce stress on water supplies and natural systems. Water harvesting practices like cisterns or rain barrels can store water to be reused.
- **Extreme heat mitigation:** CSGI can help reduce the urban heat island effect by adding vegetation into the landscape, which has a cooling effect. Planting trees provides shade and green roofs mitigate excess heat through evapotranspiration. They are both good options in highly urbanized areas.
- **Community, culture and recreation:** Many studies have shown that CSGI practices can improve quality of life, especially in urban areas. If significant water quality improvements are made (by reducing combined sewer overflows, for example), CSGI practices can improve water recreation (Stratus Consulting, 2009).
- **Water filtration/quality:** Appropriately designed CSGI can help maintain water quality in surface waters by reducing pollutant loads. Amounts or types of improvements depend on design and site conditions.

- **Sequester carbon dioxide:** CSGI techniques that include vegetation can help to absorb carbon dioxide (Spatari et al., 2011).

Possible effects of changes in climate and water levels on CSGI

Stronger Storms

- Some CSGI practices may depend on adaptive management. Re-sizing or adjustments to overflows may be needed to handle larger rain events. CSGI in new developments is typically designed to accommodate 90% of all rain events occurring each year, with 10% of rain events exceeding the design capacity. As precipitation in strong storms increases with climate change the design capacity of installed CSGI will be exceeded more often. Adjustments may be needed to design thresholds and installed CSGI systems may need to be adapted to accommodate and survive larger storms.

Warmer temperatures

- Designs for CSGI practices that include vegetation will need to consider the adaptability of selected plant species to warmer temperatures over time.

Short-term drought

- Vegetation that can withstand wet and dry soils should be considered for the long-term health of a CSGI. Operation and maintenance plans for CSGI should consider adjustments over time to respond to more extreme wetting and drying cycles, which may stress vegetation. Soils and vegetation may also need to be amended or replaced over time.

Examples of locations where CSGI techniques have been implemented

There are many examples of CSGI throughout New York State. Several websites offer case studies of a variety of project types:

- Environmental Facilities Corporation Green Innovation Grant program: *www.efc.ny.gov*
- NYS DEC Hudson River Estuary Program Green Infrastructure Program: *http://www.dec.ny.gov/lands/58930.html*
- NYC GreenStreet Program: *http://www.nyc.gov/html/dep/html/stormwater/using_green_infra_to_manage_stormwater.shtml*
- Onondaga County Save the Rain Program: *http://savetherain.us/*
- Buffalo Sewer Authority Green Infrastructure Program: *http://raincheckbuffalo.org/*
- NYS Department of Environmental Conservation Water Quality Improvement Grants: *http://www.dec.ny.gov/pubs/4774.html*

Site-Specific examples

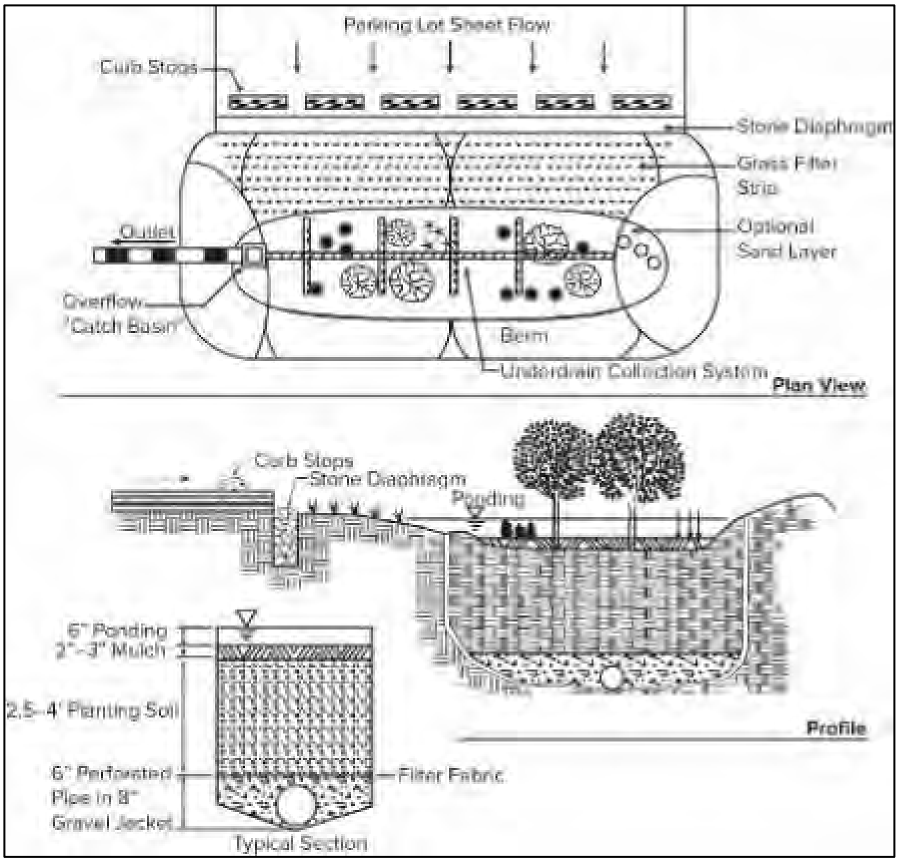
- Kingston, NY: The City of Kingston installed a rain garden to absorb rooftop runoff. *http://www.dec.ny.gov/lands/86684.html*
- Greenwood Lake, NY: The Village used vegetated swales to absorb runoff from a roof and parking lot. *http://www.dec.ny.gov/lands/73096.html*
- Yonkers, NY: The City of Yonkers used uncovered the Saw Mill River in a stream daylighting project. *http://www.yonkersny.gov/work/department-of-planning-development/projects/daylighting-of-the-saw-mill-river*
- Lake George, NY: Lake George used pervious pavement on Beach Road to infiltrate runoff before it reaches the lake. *www.efc.ny.gov/Default.aspx?tabid=452*
- New York, NY: Logan Gardens in Manhattan used a green roof to reduce rooftop runoff. *http://www.dec.ny.gov/lands/101086.html*
- Ardsley, NY: The Village of Ardsley used stormwater planter to beautify a bus shelter and capture runoff. *http://www.dec.ny.gov/lands/74996.html*
- New Paltz, NY: The SUNY New Paltz campus has cisterns to capture rooftop runoff in large underground tanks for reuse. *http://buoy.newpaltz.edu/cisterns.php*

Factors to consider in design, construction and maintenance for restoration (if a natural feature) or construction (if a nature-based feature)

- CSGI or drainage that is undersized for the location and the volume of water can be overwhelmed in smaller storms. CSGI that is oversized can result in loss of vegetation, if the vegetation doesn't have access to enough water. Water control structures may be needed to manage water storage and rate of release.
- CSGI must be designed with consideration for drainage area characteristics including runoff volume, runoff composition, including pollutants of concern, soils, depth to groundwater and bedrock. Consideration must be given to the location and depth of other infrastructure underneath (electric, water utilities, etc.) if water will be infiltrating through the ground.
- Constructed practices that infiltrate potentially contaminated road runoff shouldn't be too close to a well-field or drinking water sources. Road salt and other deicers can affect water quality and vegetation.
- Vegetation must be adaptable to both very wet and very dry conditions. Lack of maintenance can result in vegetation, debris or sediment blocking necessary conveyance paths (e.g. drainage pipes, clogged pores in porous pavement, downspouts from green roofs).
- Regular maintenance (e.g. vegetation management, clearing of debris and excess sediment) is required for all CSGI practices to allow for practices to adapt with changes in climate and precipitation.

Resources

- Detailed specifications for all practices can be found in the NYS Stormwater Management Design Manual (NYS DEC, 2015) (Figure A.18-8). http://www.dec.ny.gov/docs/water_pdf/swdm2015entire.pdf



Credit: NYS Stormwater Management Design Manual.

Figure A.18-8. Example of detailed specifications for bioretention CSGI.

Sources

1. American Rivers, the Water Environment Federation, the American Society of Landscape Architects, & ECONorthwest. (2012). Banking on Green: A Look at How Green Infrastructure Can Save Municipalities Money and Provide Economic Benefits Community-wide. Retrieved from https://www.asla.org/uploadedFiles/CMS/Government_Affairs/Federal_Government_Affairs/Banking%20on%20Green%20HighRes.pdf

2. Driscoll, C. T., Eger, C. G., Chandler, D. G., Davidson, C. I., Roodsari, B. K., Flynn, C. D., Lambert, K. F., Bettez, N. D., & Groffman, P. M. (2015). Green Infrastructure: Lessons

from Science & Practice. Retrieved from http://projects.iq.harvard.edu/files/science-policy/files/gi_report_surdna_6_29_15_final.pdf?m=1437149385

3. McPhillips, L. E., Groffman, P. M., Schneider, R. L., and Walter, M. T. (2016). Nutrient Cycling in Grassed Roadside Ditches and Lawns in a Suburban Watershed. Journal of Environmental Quality. doi: 10.2134/jeq2016.05.0178

4. McPhillips, L. E., & Walter, M. T. (2015). Hydrologic Conditions Drive Denitrification and Greenhouse Gas Emissions in Stormwater Detention Basins. Ecological Engineering, 85: 67–75. doi:10.1016/j.ecoleng.2015.10.018.

5. New York State Department of Environmental Conservation (NYS DEC). (2015). New York State Stormwater Management Design Manual. Retrieved from http://www.dec.ny.gov/docs/water_pdf/swdm2015entire.pdf

6. Nylen, N. G., & Kiparsky, M.. (2015). Accelerating Cost-Effective Green Stormwater Infrastructure: Learning from Local Implementation. Retrieved from https://www.law.berkeley.edu/files/CLEE/GSI_Report_Full_2015-02-25.pdf

7. Spatari, S., Yu, Z., & Montalto, F. (2011). Life Cycle Implications of Urban Green Infrastructure. Environmental Pollution, 159: 2174–2179.

8. Stratus Consulting. (2009). A Triple Bottom Line Assessment of Traditional and Green Infrastructure Options for Controlling CSO Events in Philadelphia's Watersheds. Retrieved from https://www.michigan.gov/documents/dnr/TBL.AssessmentGreenVsTraditionalStormwaterMgt_293337_7.pdf

A.19 – Nature-based Coastal Techniques

What are Nature-based Coastal Techniques?

Nature-based coastal techniques mimic, accommodate or enhance natural shoreline processes to reduce the risk of erosion to human assets on coastal (ocean, estuarine, bay, large river and lake) shorelines. Depending on the site location, scale and design, they may also reduce the risk of flooding. Nature-based coastal techniques rely on vegetation alone or may be combined with grading, fill or addition or removal of structural components. They are generally appropriate for shorelines that are exposed to low to moderate energy waves and currents. They may also be exposed to tides and saline environments. These techniques fall into three general categories: bank stabilization, in-water features and floodplain reconnection.

Nature-based coastal techniques generally do the following:

- Utilize natural materials and designs to achieve objectives
- Stabilize banks to prevent or minimize erosion
- Allow for access to an adequate floodplain, when possible
- Improve or create stable shoreline habitat
- Allow access to the water

In existing literature and current practice these techniques may also be referred to as hybrid, biological, bioengineered, bio-mechanical, ecologically-enhanced, semi-structural, nourished, living, soft and green.

Nature-based coastal techniques should be considered before implementing a hard structural coastal protection feature such as a bulkhead or seawall. For more information on distinctions between restored, nature-based and hard structural measures see Section 5 of the General Guidance on Natural Resilience Measures.

Examples of nature-based coastal techniques

Types of nature-based coastal techniques include, but are not limited to, the following:

- Bank stabilization
- Sediment nourishment
- In-water features
- Floodplain reconnection

Examples of nature-based coastal techniques can be found below. Additional examples and information can be found in individual coastal natural feature descriptions.

Bank stabilization

Bank stabilization techniques can be used to prevent erosion from the face and the toe of a bluff or slope and foster the re-establishment of a stable bank. Techniques include softening the slope, revegetating the bank and use of vegetation combined with other materials such as logs, rock or manmade materials.

Techniques:

- Revegetation - Seeding, sodding, or planting of grasses, perennials and/or woody vegetation (shrubs and trees) (Figure A.19-1).
- Softening slopes - Shaping, grading, or contouring of the bank to create gentler slopes that can attenuate currents, waves and wakes and facilitate the planting and establishment of vegetation.
- Reinforcing soils to support vegetation - Use of natural construction materials that are found at the site or mimic natural materials found at the site installed in specific configurations that offer immediate erosion protection and reinforcement of soils, at the toe or on the slope. In time, these methods support the establishment of vegetation and a root network that stabilizes sediment. Illustrations of these techniques can also be found in nature-based stream techniques.
- Live cuttings or live branch cuttings - Branches cut from native trees or shrubs and used immediately for live cribwalls, vegetated geogrids or to make live fascines (Figure A.19-3 and Figure A.19-8).
- Live fascines or wattles - Long bundles of live branch cuttings bound together in cylindrical structures. They are placed in shallow trenches parallel to the shoreline contour on dry slopes and at an angle on wet slopes to reduce erosion and shallow sliding of the slope face (USDA NRCS, 1996, p. 16–16) and covered with soil. They will sprout roots and grow (Figure A.19-2 and Figure A.19-3).
- Live stakes and dead stout stakes – Live stakes are sections of branches without twigs or leaves that may be pounded directly into the soil that will then root and leaf out to protect a slope or bank. They can be used on their own or to anchor other elements. Willows and shrub dogwoods are typical species. Dead stout stakes are made of dry (dead) branches or lumber and used to anchor elements (Figure A.19-3, Figure A.19-6, and Figure A.19-8).
- Brush mattresses - A brush mattress is a combination of live stakes, live fascines and branch cuttings installed to cover and stabilize banks. Application typically starts above bank-forming flow conditions and moves up the slope (USDA NRCS, 1996, p. 16–30) (Figure A.19-3).

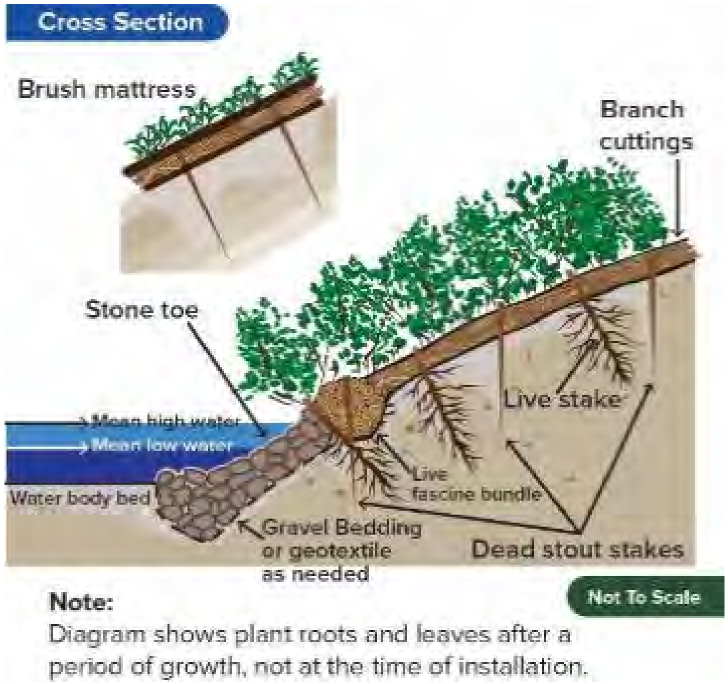
- Dormant post plantings - Dormant post plantings form a permeable stabilized slope that is constructed from rootable vegetative material placed along streambanks in a square or triangular pattern (USDA NRCS, 1996, p. 16–38). It is installed in the dormant season, the time of year when plants are not growing and deciduous plants shed their leaves (USDA NRCS, 1996, p. 16–85). When the growing season returns the plantings root and grow. See illustration in nature-based stream techniques.
- Joint plantings: Joint planting, or vegetated riprap, involves tamping live stakes into joints or open spaces in rocks that have been previously placed on a slope. Alternatively, the stakes can be tamped into place at the same time that rock is being placed on the slope face (USDA NRCS, 1996, p. 16-28). It is also referred to as rip-rap with live stakes.
- Live crib walls: A box-like interlocking arrangement of untreated log or timber members. The structure is filled with suitable backfill material and layers of live branch cuttings that root inside the crib structure and extend into the slope. Once the live cuttings root and become established, the subsequent vegetation gradually takes over the structural functions of the wood members (USDA NRCS, 1996, p. 16–25) (Figure A.19-4).
- Toe protection using fiber logs: Toe protection is material used to protect or armor the toe of a bank, where the slope meets the bed of the waterbody (USDA NRCS, 1996, p. 16–88). Material can be fiber logs or rolls, stone, or timber. A fiber roll is a coconut fiber (coir), straw, or excelsior woven roll encased in netting of jute, nylon, or burlap used to dissipate energy along bodies of water and provide a good medium for the introduction of vegetation. The roll is anchored into the bank and, after suitable backfill is placed behind the roll, herbaceous or woody vegetation can be planted. (Figure A.19-5 and Figure A.19-6).
- Log, rootwad, tree and boulder revetment: A revetment is a facing of armoring material shaped to conform to and protect a shoreline (USDA NRCS, 1996, p. 16–87). These revetments are systems composed of logs, rootwads (a tree trunk or root mass), whole trees and boulders selectively embedded in and on banks (USDA NRCS, 1996, p.16–87). Whole trees are usually cabled together and anchored by earth anchors, which are buried in the bank. Each approach can provide excellent overhead cover, resting areas, shelters for insects and other fish food organisms, substrate for aquatic organisms and water velocity that results in sediment flushing and deeper pools (NRSC 1996, p. 16-36) (Figure A.19-7) See also illustration in nature-based stream techniques.
- Vegetated geogrid – A vegetated geogrid is a system of successive soil lifts or layers, wrapped in a synthetic or natural fiber material with live branch cuttings placed between layers (Allen et al., 2006, modified from USDA NRCS, 1996) (Figure A.19-8)

Credit: New England Environmental, Inc.

Figure A.19-1. Native vegetation was used to stabilize this bluff slope. Temporary structures were used to protect the vegetation until the root systems became fully established.

Credit: GEI Consultants Inc., Brian Majka.

Figure A.19-2. Nature-based bluff restoration in Glenn, Michigan.
Upper left photo: Eroded bluff; April 2007. Top right photo: slope stabilized with stacked straw wattles to create terracing and densely planted with native switch grass, little bluestem, willows and dogwoods; August 2008. Lower photo: mature vegetation on stabilized slope; October 2015.



Credit: Adapted from USDA NRCS (1996).

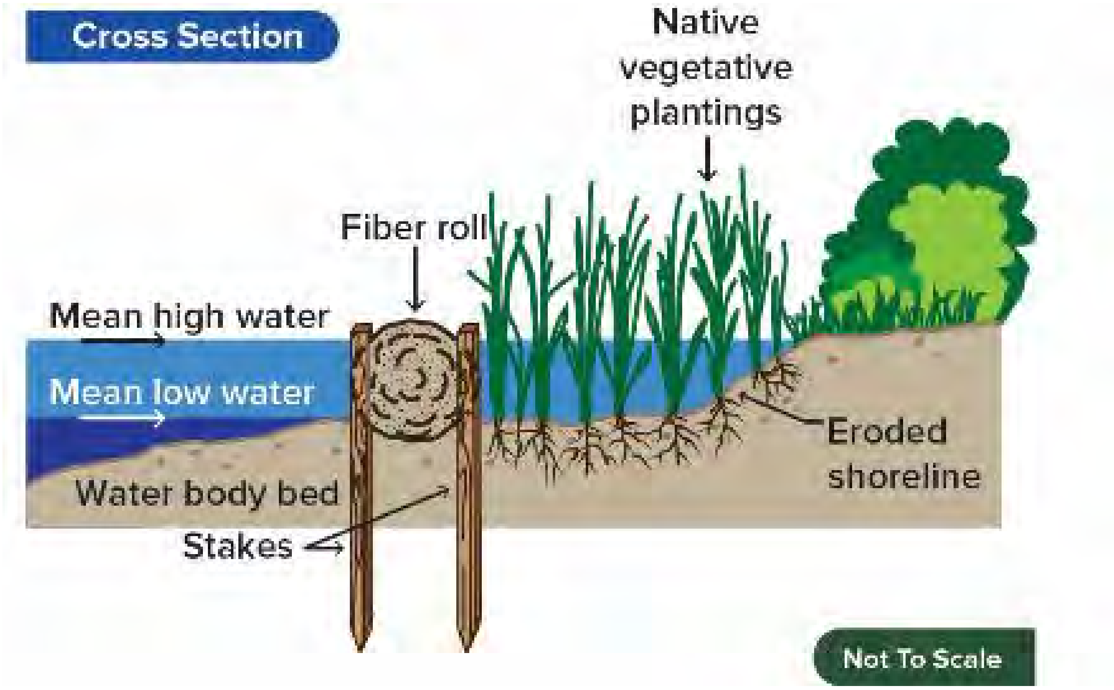
Figure A.19-3. Slope protection using brush mattress, live and dead stout stakes, live fascines and stone toe protection.
The brush mattress consists of the live fascines, oriented parallel to the shoreline and branch cuttings. It is anchored with both live and dead stakes. The stone toe protects the base of the structure until it becomes established.

Credit: GEI Consultants, Inc.

Figure A.19-4. Live crib wall monitored for five years at Stony Brook Harbor, NY. Upper left: installed in 2009; upper right: one year later; lower left: three years later; lower right: five years later.

Credit: Dave Bushek.

Figure A.19-5. Fiber roll and bagged shell edging.
The fiber rolls protect vegetation from wave action and allow root systems to become established. The bagged shell stabilizes the base of the structure.



Credit: USDA NRCS (1996).

Figure A.19-6. Cross-section of slope protection using fiber roll, stakes and native vegetation plantings.
The dead stakes anchor the fiber roll, which protects the vegetation from wave action until root systems are established

Credit: NYS DEC.

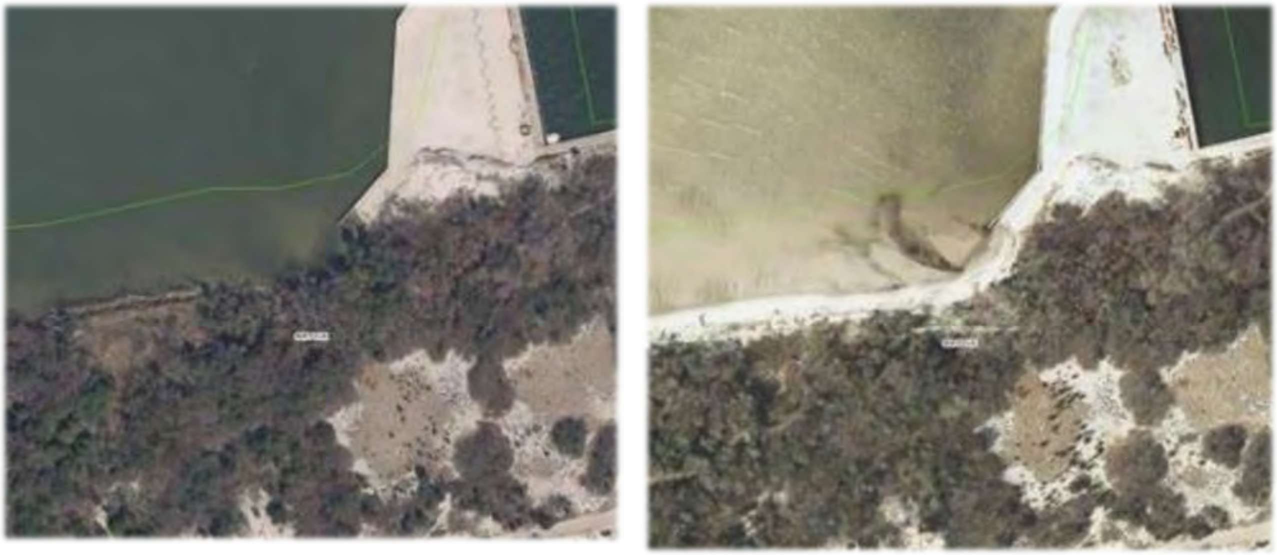
Figure A.19-7. Lagoon of Strawberry Island in the Niagara River.
Tree trunk and rootwad installed and anchored in water to act as a low-profile sill that will attenuate waves and currents. Vegetation has become established behind the tree along the shoreline.

Credit: Adapted from USDS NRCS (1996).

Figure A.19-8. Slope protection using vegetated geogrid, live and dead stout stakes, live cuttings and stone toe protection.
The vegetated geogrid is layers of soil wrapped in fabric. The cuttings will grow a stabilizing root system. The stone toe protects the base of the structure from erosion until it becomes established. The stakes anchor other elements.

Sediment Nourishment

Where there exists significant potential for flood and erosion risk reduction and ecological gain, fill may be used to nourish a beach, dune, shoal or tidal wetland. Nourishment should aim to restore natural processes and, with the exception of beach nourishment, be coupled with vegetative plantings (Figure A.19-9 and Figure A.19-10).



Credit: NYS DEC.

Figure A.19-9. Recreational beaches may be augmented by mechanically or hydraulically placing sand adjacent to or directly on an eroding beach.
These before and after photos show feeder beach sand placement at Sailor's Haven on Long Island. A large volume of sand was added from an outside source to an eroding beach to widen the beach and move the shoreline seaward. The design takes advantage of natural longshore sediment transport processes and over time the sediment moves along the shoreline to "feed" the adjacent shoreline area.

Credit: NYS DOS.

Figure A.19-10. This constructed nature-based dune on Long Island includes planted dune grass and sand fencing to capture and retain sand.

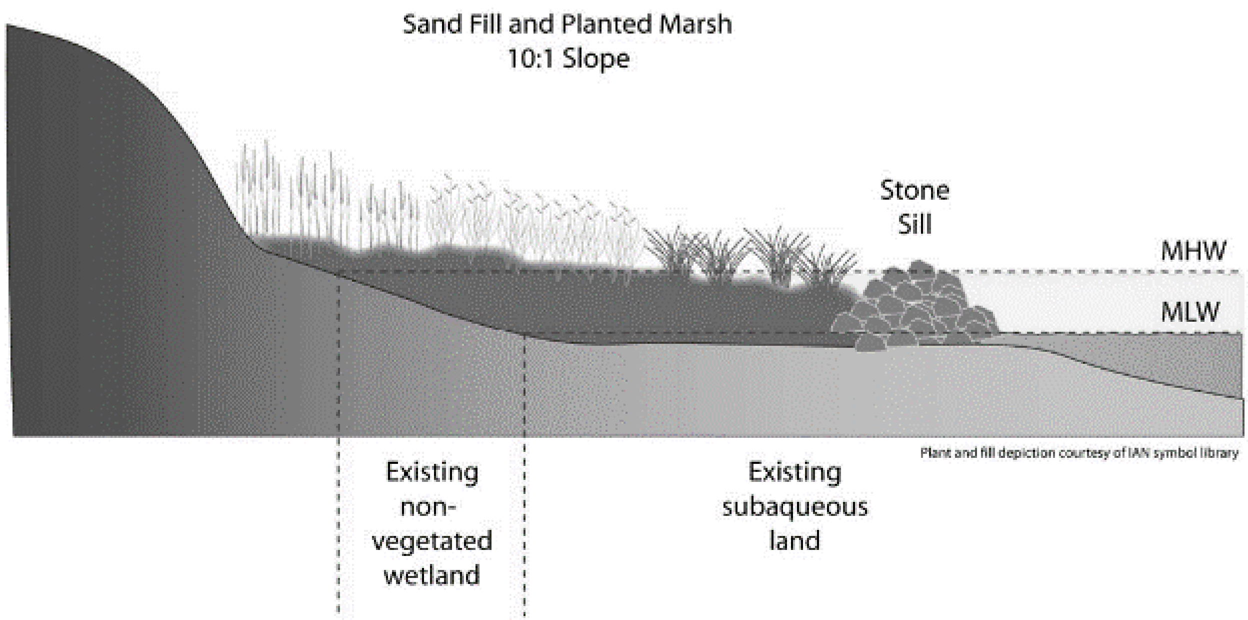
In-water features

In-water structures can be combined with planting of vegetation or features that enhance shellfish colonization to attenuate waves and protect aquatic habitat or the inland shore from erosion. Note: In-water structural components may not be considered nature-based features if they significantly reduce or eliminate natural longshore, cross-shore or offshore sediment transport, or if they inhibit cross-island sediment transport on barrier islands.

- Low profile sills are nearshore wave attenuators and may be used in medium to low energy environments within lake, large riverine and estuarine systems (Figure A.19-11 and Figure A.19-12). These low-crested continuous or discontinuous structures are placed parallel to the shore to protect landward vegetation. They can be either temporary, to allow vegetation to establish, or permanent.

  Sills can be made of a variety of materials including broken rock or cobbles or, in marine waters, bagged or loose shell, or other substrates. Constructed sills typically have a trapezoidal cross-section and may have breaks or offsets in the linear structure or changes in crest height to allow fin and shellfish movement and tidal exchange.

❖ Nature-based shellfish reef restoration can include bagged or loose shell and manufactured concrete structures which encourage shellfish and other marine organisms to colonize the surfaces, grow and settle (Whalen et al., 2011). Nature-based shellfish reefs can also be used to augment low-profile sill construction. Projects designed to support naturally productive shellfish beds need to include appropriate considerations for how water quality, water circulation and benthic substrate may affect survival. Shellfish enhancement measures (adding juvenile or adult shellfish) to bottom habitats have been used to supplement declining natural populations.



Credit: Virginia Institute of Marine Sciences, K. Duhring.

Figure A.19-11. A diagram of marsh sill. Stone structures parallel to the shoreline allow vegetation to establish root systems that stabilize the wetland feature.

Credit: NYS DEC.

**Figure A.19-12. This nature-based shoreline is located on the Hudson River in Coxsackie, NY.
Rock clusters parallel to the shoreline (parallel to red line) serve as a low-profile sill to reduce wave energy. The slope is stabilized with tiers of rock between rows of deep-rooted vegetation.**

Floodplain reconnection and stabilization

These techniques aim to reestablish connectivity between the waterbody and its floodplain. They may include removal of manmade flood protection such as berms, levees or dikes, removal of fill, or reduction of impervious surfaces, including structures and pavement. Approaches may include regrading of the slope in areas adjacent to the shoreline to allow more water to access the floodplain and may include shoreline or floodplain stabilization structures that incorporate vegetation, natural materials and rock. It can also include restoration of tidal and non-tidal wetlands or other natural features. It may be combined with constructed stormwater green infrastructure techniques on site or above the floodplain to capture and slowly release floodwaters.

Techniques:

- Planned and controlled removal of flood protection structures to reconnect a coastal shoreline to its floodplain can create large flood storage areas that also serve as significant wildlife habitat.
- Moving or siting levees or other flood protection structures back from the shoreline can allow coastal areas to connect to some floodplain area while still providing flood

protection to densely developed areas. Planting of native shrubs and grasses in these controlled floodplain areas can provide habitat value.

- A floodplain area can be excavated to offset the vertical difference between floodplain and water levels, increasing water storage. Vegetation and natural materials can be used to add habitat value to the new floodplain area. Constructed stormwater green infrastructure techniques may also be used to capture and slowly release floodwaters.

How do nature-based coastal techniques reduce risk?

This nature-based feature should be designed to mimic or be enhanced by natural features and processes in stream, river, estuarine, lake, or ocean coastal systems. The greatest risk reduction benefit is achieved when the larger natural system is conserved or maintained. Risk reduction will vary based on management of these individual features. Other measures may be needed to further reduce risk from large surge or flood events.

Below are examples of how nature-based coastal techniques mimic the risk reduction benefits of natural features:

- **Serve as a barrier:** Similar to natural banks, nature-based shorelines contain normal water flows and confine drainage pathways within the floodplain until they are overtopped. Stable shorelines break current, wave and wake energy. In-water features, like low profile sills, mimic tidal and non-tidal wetlands by reducing or dissipating wave energy, protecting vegetation and reducing the rate of erosion.
- **Reduce water velocity:** Nature-based shoreline stabilization measures and in-water structures reduce the force of currents and waves. Roots of aquatic vegetation hold and stabilize the soil. Stems of plants reduce waves and surge through friction.
- **Stabilize sediment:** Shorelines with established vegetation reduce water velocity and bind sediment with their root systems. In-water structures and aquatic plants allow sediment to settle out and accumulate on their landward side. Recent studies have shown that nature-based techniques fared well during storm surge events (Miller and Rella, 2015) and that "marshes with and without sills are more durable and may protect shorelines from erosion better than bulkheads in a Category 1 storm" (Gittman et al., 2014).
- **Supply sediment:** Shorelines stabilized using nature-based approaches can still supply sediment to the system, by allowing for sediment to bypass the structure. The amount of sediment supply can vary depending on the project goals and approach. An adequate sediment supply is necessary to sustain downstream or adjacent shoreline features including wetlands, shoals and beaches.

Forces and conditions that nature-based coastal features can mitigate to reduce risks to people and communities

- Currents generally parallel to the shoreline causing damage from erosion, floating debris or the mobilization of ice.
- Waves, wakes and surges generally perpendicular to the shoreline causing damage from erosion, floating debris, or the mobilization of ice
- Precipitation or meltwater moving downhill to nearest waterbody causing erosion, temporary pooling and localized property damage
- Temporarily elevated water levels from surge, high river flows, or high lake levels inland of the shoreline causing property damage

Human activities that reduce or impair risk-reduction capacity

- Strong boat wakes and vandalism may dislodge vegetation and structural components.
- Inadequate protection from grazing of domestic animals can lead to vegetation loss.
- Incompatible adjacent land uses and run-off from upland stormwater can increase erosion and destabilize the structure.
- Hard structural approaches in adjacent and nearby areas may interrupt sediment transport and reduce sediment supply, impairing risk reduction capacity.
- Improper siting of offshore dredging sand sources may reduce sediment supply to adjacent areas and diminish the sand/sediment supplied to the beach leaving the shoreline more susceptible to erosion.
- Interruption of sediment supply (e.g. through use of jetties and groins) could impair the erosion risk reduction capacity

Other benefits

Nature-based coastal techniques provide a range of other benefits, including the following:

- **Economic:** These techniques can protect infrastructure and property from erosion while providing other ecological services and accommodating some water-dependent uses. Sill maintenance costs can be lower than bulkhead maintenance costs (R. Gittman personal communication, 2016). Nature-based techniques can reduce the negative effects of erosion management on downdrift shoreline reaches. In contrast to many hard structural measures that increase water reflection and the risk and cost of downdrift erosion, most nature-based features incorporate vegetation, which can slow water velocity and sediment movement, but still allow some sediment to continue to supply downdrift areas.

- ➔ **Habitat:** Nature-based shorelines allow for land to water connectivity and provide habitat for terrestrial and aquatic species (Strayer and Findlay, 2010). Physically diverse shorelines (e.g. vegetation, bank irregularities, sediment particles of different sizes) create aquatic and terrestrial habitat (FISRWG, 1998). In-water structures may be suitable habitat for encrusting organisms, oyster shell can provide substrate for oysters, native marsh vegetation provides habitat for invertebrates, fish and birds. Gittman et al. (2016) found that living shorelines, including marsh sills can enhance ecosystem services including the provision of nursery habitat.
- ➔ **Extreme heat mitigation:** Vegetated natural areas can mitigate extreme heat and the urban heat island effect by providing shade and/or through the cooling effect of evapotranspiration, which releases water vapor (and heat energy) to the atmosphere.
- ➔ **Community, culture and recreation:** Can accommodate access to waterways and water-dependent uses including boating, fishing, swimming and wildlife viewing.
- ➔ **Water filtration/quality:** Vegetated shorelines can slow and filter runoff. They can sequester and convert excess nutrients through biochemical processes benefitting water quality. Nature-based tidal and non-tidal wetlands are able to filter nutrients from upland sources.
- ➔ **Sequester carbon dioxide:** Woody and wetland vegetation along shorelines store carbon. Davis et al. (2015) found that low profile sills with marshes sequester carbon.

Possible effects of changes in climate and water levels on nature-based coastal techniques

Sea-level rise/water-level change

- Nature-based shoreline stabilization structures only reduce risk of flooding up to the top of the shoreline or bank. Some can be built to raise the top of the bank and adapt to higher flood waters or sea-level rise, however, building higher structures creates a barrier that flood water can overtop and become trapped behind (Rella and Miller, 2012; USACE, 2011). Some in-water structures can be manually elevated as mean sea level increases (NACCS, 2015).
- Sills are designed to allow sediment to deposit shoreward and wetlands to accrete, or raise in elevation, over time (NACCS, 2015). However, if sediment supply is limited or there is a landward barrier that prevents inland migration of the wetland, a rapid change in sea level may outpace the ability of a tidal wetland to build up or move laterally behind a sill. Sediment nourishment may be needed to ensure the survival of the wetland.
- Oyster/mussel bed components may be able to keep up with sea-level rise, but may need management to limit vulnerability to increasing ocean acidification.

Stronger Storms

- Disturbance from strong storms can promote invasive species colonization. Some invasive species may not be able to provide sufficient root structure to prevent soil erosion. Proper maintenance is needed to ensure that invasive plants do not dominate shoreline habitat.

Warmer temperatures

- Planting schemes will need to consider the survivability and adaptability of selected plant species to warmer temperatures over time.

Short-term drought

- Drought may increase the need for vegetation management along the bank. If vegetation dies and is not replanted it will reduce stabilization of the bank.

Examples of locations where restored or nature-based coastal techniques have been implemented

- The Rockaways, NY: Dunes have been planted with native vegetation to stabilize sand *https://www.rwalliance.org/rwa/projects/projects_4/*
- Delaware: This marsh restoration project used a spray of dredged sediment to nourish a tidal wetland *http://www.dnrec.delaware.gov/News/Pages/DNRECs-first-beneficial-reuse-marsh-restoration-project-succeeds-with-thin-layer-spray-application.aspx*
- Coxsackie, NY: This nature-based shoreline includes a vegetated terrace, rock sill and sunken ship to protect shoreline adjacent to a boat launch on the Hudson River in Greene County (see Figure A.19-3 above) *https://www.hrnerr.org/doc/?doc=240189567*
- Strawberry Island, NY: A tree with root wad was anchored in the river to act as a low profile sill and attenuate waves in a lagoon of the Niagara River (see Figure A.19-2 above): *https://www.hrnerr.org/estuary-training/trainingtopic/sustainable-shorelines-designs-webinar-series/*
- Yonkers, NY: A sill made of rock enclosed in nets was used to foster wetland habitat at Habirshaw Park *https://www.hrnerr.org/hudson-river-sustainable-shorelines/demonstration-site-network/ and http://sagecoast.org/*.
- New York City, NY: A wetland was planted behind a remnant pier in Brooklyn Bridge Park. *http://www.brooklynbridgepark.org/pages/gardens#salt-marshes*
- Long Island, NY: Beach nourishment at Sailor's Haven *https://www.nps.gov/fiis/learn/nature/upload/Sailors-Haven-Restoration-version-4.pdf*
- Tillamook, OR: The Southern Flow Corridor project, supported by federal, state and local partners, acquired three floodplain properties and removed a series of levees and dikes to restore almost 400 acres of estuarine floodplain. The project reduced flood risk to

Tillamook city and county and increased spawning habitat for native salmon populations. https://tillamookoregonsolutions.com/resources-4/

Examples can be found in other areas including Delaware Bay, Maryland, Virginia, North Carolina and Mobile Bay in Alabama.

Factors to consider in design, construction and maintenance for restoration (if a natural feature) or construction (if a nature-based feature)

- Aim to imitate the diversity of natural materials and structures on undeveloped shorelines adjacent to the site. Include natural buffer zones between manicured areas, such as lawns, and the shoreline.
- Design for a gradually sloping shoreline, wherever possible, to absorb the energy of wakes and waves.
- Upland slope and stormwater drainage conditions are important to understand. Concentrated surface water runoff and seepage can cause down-cutting or failure of the bank slope. Constructed stormwater green infrastructure techniques can be used to intercept stormwater to prevent it from flowing down the face of a bluff or slope.
- Vegetation Considerations:
  - Plantings should be temporarily protected until they are established.
  - Typically, the eroded shoreline will need to be graded back prior to the installation of bioengineered approaches.
  - If woody vegetation is being used, the seasonality of harvesting and installing plant cuttings should be considered (e.g. some cuttings should be installed during the plant's dormant season).
  - Stabilization projects should be monitored regularly, and especially after extreme weather events and the winter season. Routine maintenance carried out including controlling invasive species and re-planting native species that fail to thrive.
  - Plants should be nurtured and protected in the early stages of growth from grazing domestic and wild animals.
  - Large woody debris and wrack (debris) play important ecological roles along natural and stabilized shorelines and should therefore remain in place (Strayer and Findlay, 2010).
- Low-profile sills provide erosion protection in sheltered areas with low to moderate erosion rates and moderate tidal range (where applicable). They are built in shallow areas with low to moderate slopes. The crest of the sill should be about 1 foot above mean high water (MHW) (Miller et al., 2016) or in higher energy environments > 1 foot

above MHW (Duhring et al., 2006, p. 23). Vegetation should be native to the area and able to withstand inundation. Other factors to consider in the design of this feature include: upland slope, nearshore slope, nearshore depth, width of marsh created and energy concerns including wake energy, ice and fetch. If shellfish are included in the design, then appropriate salinity and other factors relevant to survival must be considered.

- Site-specific designs and follow up maintenance of sills are important to ensure that sediment accumulation is sufficient. Sill structures should be inspected for displacement of components, settling of the structure and scour and erosion, especially after storms and after winter ice (Miller et al., 2016). Vegetation maintenance includes replacement of plants that fail to thrive.
- Property ownership, including the ownership of the underwater lands, must be considered on a site by site basis when designing and permitting of in-water structures. The rights of the public to access public waters and natural resources, freedom of use and rights to pass through or navigate the nearshore area, its waters and resources, may constrain options.
- Consult the appropriate regulatory agencies before design of any nature-based coastal project.

Resources

- There are many sources of engineering guidance for nature-based shoreline stabilization including the U.S. Army Corps of Engineers, USDA Natural Resources Conservation Service and Soil and Water Conservation Districts. See reference list for full citations for the following:
  - Allen et al. (2006)
  - Allen and Leech (1997)
  - Hardaway et al. (2010)
  - Miller et al. (2016)
  - USDA (1996)
  - Rella and Miller (2012)
- NYS DEC guidance documents can be found at the links below:
  - *Guidelines for Design of Structures along NYS Coastlines*
  - *Shoreline Stabilization: Ecological Importance of Natural Shorelines and Proper Shoreline Stabilization*
  - *Shoreline Stabilization Techniques*
  - *Shoreline Stabilization – Interpretive Guidance to Staff*

- *Sample Project Plans for Protection of Waters and Wetland Permit Applications*
- *New York Standards and Specifications for Erosion and Sediment Control*
- *Tidal Wetlands Guidance Document: Living Shoreline Techniques in the Marine District of New York State*

❖ For Hudson River specific literature reviews, see Allen et al. (2006), Rella and Miller (2012) and the Hudson River Sustainable Shorelines website: *https://www.hrnerr.org/hudson-river-sustainable-shorelines/*

Sources

1. Allen, G., Cook, T., Taft, E., Young, J., & Mosier, D. (2006). *Hudson River Shoreline Restoration Alternatives Analysis*. Prepared by Alden Research Laboratory, Inc. and ASA Analysis and Communications, Inc. for the Hudson River National Estuarine Research Reserve.

2. Allen, H. H., & Leech, J. R. (1997). Bioengineering for Streambank Erosion Control: Report 1—Guidelines (Technical Report EL-97-8). Vicksburg, MS: U.S. Army Corps of Engineers Waterways Experiment Station.

3. Davis, J. L., Currin, C. A., O'Brien, C., Raffenburg, C., & Davis, A. (2015). Living Shorelines: Coastal Resilience with a Blue Carbon Benefit. PloS one, 10(11): e0142595.

4. Duhring, K.A., Barnard, T.A., & Hardaway, S. (2006). A Survey of the Effectiveness of Existing Marsh Toe Protection Structures in Virginia: Final Report to the Keith Campbell Foundation for the Environment, Inc., Center for Coastal Resources Management and VIMS: Shoreline Studies Program.

5. Federal Interagency Stream Restoration Working Group (FISRWG). (1998). Stream Corridor Restoration: Principles, Processes, and Practices. Retrieved from *http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044574.pdf*

6. Fischenich, C. (2001). Stability Thresholds for Stream Restoration Materials. EMRRP Technical Notes Collection (ERDC TNEMRRP-SR-29). Vicksburg, MS: U.S. Army Engineer Research and Development Center.

7. Gittman, R. K., Peterson, C. H., Currin, C. A., Fodrie, F. J., Piehler, M. F., & Bruno, J. F. (2016). Living Shorelines Can Enhance the Nursery Role of Threatened Estuarine Habitats. Ecological Applications, 26(1): 249–263.

8. Gittman, R. K., Popowich, A. M., Bruno, J. F., & Peterson, C. H. (2014). Marshes with and Without Sills Protect Estuarine Shorelines from Erosion Better Than Bulkheads During a Category 1 Hurricane. Ocean & Coastal Management, 102: 94–102. doi: 10.1016/j.ocecoaman.2014.09.016.

9. Hardaway, C., Milligan, D., & Duhring, K. (2010). Living Shoreline Design Guidelines for Shore Protection in Virginia's Estuarine Environments, Special Report in Applied Marine Science and Ocean Engineering No. 421. Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA.

10. Lake, D. W., Jr., and New York State Department of Environmental Conservation (NYS DEC). (2016). New York State Standards and Specifications for Erosion and Sediment Control (The Blue Book). Retrieved from *http://www.dec.ny.gov/docs/water_pdf/2016nysstanec.pdf*

11. Miller, J. K., Rella, A., Williams, A., & Sproule, E. (2016). Living Shorelines Engineering Guidelines (originally published 2015). Stevens Institute of Technology. Prepared for the New Jersey Dept. of Environmental Protection.

12. Miller, J. K., & Rella, A. (2015). Forensic Analysis: Common Project Performance Factors. Stevens Institute of Technology, Hoboken, NJ; in association with and published by the Hudson River Sustainable Shorelines Project, Staatsburg, NY. Retrieved from *https://www.hrnerr.org/shorelinesforensicanalysis/*

13. North Atlantic Coast Comprehensive Study (NAACS). (2015). Resilient Adaptation to Increasing Risk. Retrieved from *http://www.nad.usace.army.mil/CompStudy*.

14. National Oceanic and Atmospheric Administration (NOAA). (2015). Guidance for Considering the Use of Living Shorelines. Living Shorelines Workgroup. Retrieved from *http://www.habitat.noaa.gov/pdf/noaa_guidance_for_considering_the_use_of_living_shorelines_2015.pdf*

15. New York State Department of Environmental Conservation (NYS DEC). (2010). Shoreline Stabilization Techniques. Retrieved from *http://www.dec.ny.gov/docs/permits_ej_operations_pdf/stabiltechguid.pdf*

16. New York State Department of Environmental Conservation (NYS DEC). (2018). Tidal Wetlands Guidance Document: Living Shoreline Techniques in the Marine District of New York State. Retrieved from *http://www.dec.ny.gov/docs/fish_marine_pdf/dmrlivingshoreguide.pdf*

17. New York State Department of Environmental Conservation (NYS DEC). (n.d.-a). Guidelines for Design of Structures along NYS Coastlines. Retrieved from *http://www.dec.ny.gov/docs/water_pdf/designguidecoastal.pdf*

18. New York State Department of Environmental Conservation (NYS DEC). (n.d.-b). Shoreline Stabilization Ecological Importance of Natural Shorelines and Proper Shoreline Stabilization. Retrieved from: *http://www.dec.ny.gov/docs/permits_ej_operations_pdf/shorestabil.pdf*

19. New York State Department of Environmental Conservation (NYS DEC). (n.d.-c). Sample Project Plans for Protection of Waters and Wetland Permit Applications. Retrieved from *http://www.dec.ny.gov/permits/70934.html*

20. New York State Department of Environmental Conservation (NYS DEC). (n.d.-d). Guidelines for Post-flood Stream Construction. Retrieved from *http://www.dec.ny.gov/docs/administration_pdf/postfloodguid.pdf*

21. New York State Department of Environmental Conservation (NYS DEC). (n.d.-d). Stream Crossings: Guidelines and Best Management Practices. Retrieved from *https://www.dec.ny.gov/docs/permits_ej_operations_pdf/streamcrossbmp.pdf*

22. New York State Department of Environmental Conservation (NYS DEC) Bureau of Habitat. (2006). Shoreline Protection Interpretive Guidance to Staff. Aquatic Habitat Protection Program. *http://www.dec.ny.gov/permits/6042.html*

23. Nordstrom, K. F., Jackson, N. L, & Farrell, E. J. (2016). Evaluation of the effects of a demonstration project for restoring bayside sediment processes at Sailors Haven Marina. Natural Resource Report NPS/FIIS/NRR-2016/1309. National Park Service, Fort Collins, Colorado. Retrieved from: *https://irma.nps.gov/DataStore/Reference/Profile/2235310*

24. Northwest Regional Planning Commission. (2003). The Shoreline Stabilization Handbook. St. Albans, Vermont.

25. Rella, A., & Miller, J. (2012). Engineered Approaches for Limiting Erosion along Sheltered Shorelines. Stevens Institute of Technology, in association with and published by the Hudson River Sustainable Shorelines Project, Staatsburg, NY 12580. Retrieved from *https://www.hrnerr.org*.

26. Strayer, D., & Tumblety, L. (2015). Managing Shore Zones for Ecological Benefits: Handbook. In association with the Hudson River Sustainable Shorelines Project, Staatsburg, NY 12580. Retrieved from *https://www.hrnerr.org*.

27. Strayer, D .L., & Findlay, S. E. G. (2010). The Ecology of Freshwater Shore Zones. Aquatic Sciences, 72: 127–163.

28. U.S. Army Corps of Engineers (USACE). (2011). Sea-level Change Considerations for Civil Works Programs. Department of the Army Engineering Circular No. 1165-2-212, 1 October 2011.

29. U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). (1996). Part 650 Engineering Field Handbook, Chapter 16 Streambank and Shoreline Protection. Aberdeen, ID. Retrieved from *http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17553.wba*.

30. Whalen, L., Kreeger, D., Bushek, D., Moody, J., & Padeletti, A. (2011). Practitioner's Guide to Shellfish-Based Living Shorelines for Salt Marsh Erosion Control and Environmental Enhancement in the Mid-Atlantic. PDE Report #11-04. Retrieved from *http://delawareestuary.org/pdf/Living%20Shorelines/Final_DELSI%20Practitioners%20Guide_2012.pdf*

A.20 – Nature-based Stream Techniques

What are Nature-based Stream Techniques?

Nature-based stream techniques mimic, accommodate or enhance natural shoreline processes to reduce the risk of erosion to human assets on stream and riverine shorelines. Depending on the site location, scale and design, they may also reduce the risk of flooding. Nature-based stream techniques rely on vegetation alone or combined with grading, fill or addition or removal of structural components. These techniques are generally appropriate for shorelines that are exposed to low to moderate energy currents with little to no fetch or wind-driven waves. They are designed to mimic or integrate with natural stream shape (morphology), water movement (hydrology) and sediment transport processes. They include a wide variety of approaches that fall into three general categories: stream stabilization techniques (bank and bed), floodplain reconnection and stream daylighting.

Nature-based stream techniques generally do the following:

- Utilize natural materials and designs to achieve objectives
- Stabilize the bed and banks to prevent or minimize erosion
- Allow water to access the floodplain, when possible
- Improve or create stable riparian habitat
- Allow access to the water

In existing literature and current practice, these practices may be referred to as natural channel design, biological, bioengineered, bio-mechanical, semi-structural, living, soft and green.

Nature-based stream and riverine techniques should be considered before implementing a hard structural stream protection feature such as a bulkhead or wall. For more information on distinctions between restored, nature-based and hard structural measures see Section 3 of the NRM General Guidance.

Examples of nature-based stream techniques

Types of nature-based stream techniques include, but are not limited to, the following:

- Stream bank stabilization
- Stream bed stabilization
- Floodplain reconnection

- Stream daylighting

Examples of nature-based stream techniques can be found below. Many of the techniques described in nature-based coastal techniques can be used for stream banks. Additional examples and information can be found in individual stream-related natural feature descriptions.

Stream bank stabilization

Bank stabilization techniques can be used to prevent erosion from the face and the toe of a slope and foster the re-establishment of vegetation and a stable stream bank. Techniques include revegetating the bank, softening the slope and use of vegetation combined with other materials such as logs, rock or manmade materials.

Techniques:

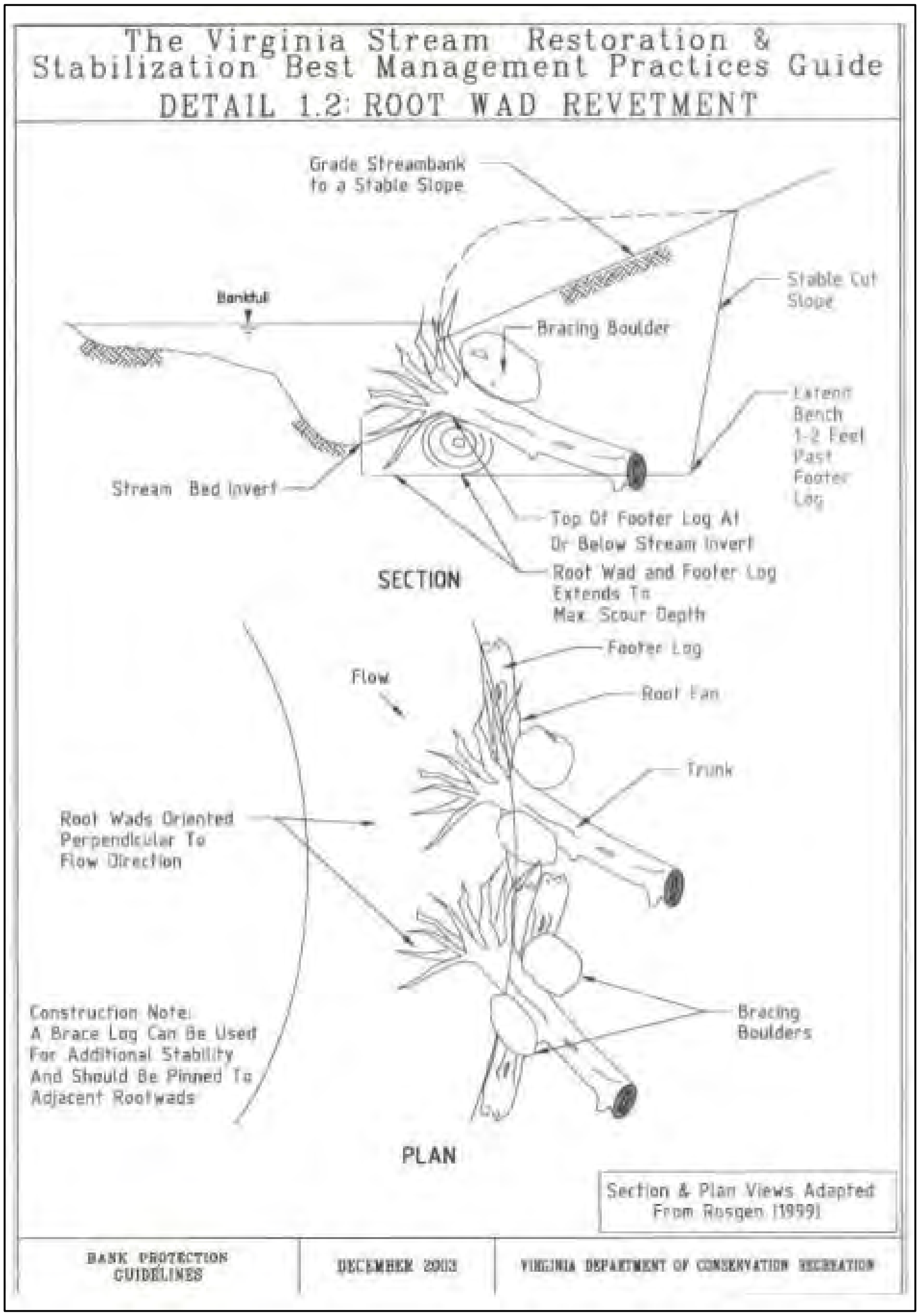
- Revegetation - Seeding, sodding or planting of grasses, perennials and/or woody vegetation (shrubs and trees).
- Softening slopes - Shaping, grading or contouring of the bank to create gentler slopes that can attenuate currents and facilitate the planting and establishment of vegetation
- Reinforcing soils to support vegetation - Use of natural construction materials found at the site or that mimic natural materials found at the site installed in specific configurations that offer immediate erosion protection and reinforcement of soils, at the toe or on the slope. In time, these methods support the establishment of vegetation and a strong root network that stabilizes sediment. Below are some examples of common methods that can be used alone or in combination. Illustrations of these techniques can also be found in nature-based coastal techniques.
  - Live cuttings or live branch cuttings - Branches cut from native trees or shrubs and used immediately for live cribwalls, vegetated geogrids or to make live fascines. See illustration in nature-based coastal techniques.
  - Live fascines or wattles - Long bundles of live branch cuttings bound together in cylindrical structures. They are placed in shallow trenches parallel to the shoreline contour on dry slopes and at an angle on wet slopes to reduce erosion and shallow sliding of the slope face (USDA NRCS, 1996, p. 16–16) and covered with soil. They will sprout roots and grow.
  - Live stakes and dead stout stakes – Live stakes are sections of branches without twigs or leaves that may be pounded directly into the soil that will then root and leaf out to protect a slope or bank. They can be used on their own or to anchor other elements. Willows and shrub dogwoods are typical species. Dead stout stakes are made of dry (dead) branches or lumber and used to anchor elements.

- Brush mattresses - A brush mattress is a combination of live stakes, live fascines and branch cuttings installed to cover and stabilize streambanks. Application typically starts above bank-forming flow conditions and moves up the slope (USDA NRCS, 1996, p. 16–30). See illustration in nature-based coastal techniques.
- Dormant post plantings - Dormant post plantings form a permeable stabilized slope that is constructed from rootable vegetative material placed along streambanks in a square or triangular pattern (USDA NRCS, 1996, p. 16–38). It is installed in the dormant season, the time of year when plants are not growing and deciduous plants shed their leaves (USDA NRCS, 1996, p. 16–85). When the growing season returns the plantings root and grow (Figure A.20-1).
- Joint plantings: Joint planting, or vegetated riprap, involves tamping live stakes into joints or open spaces in rocks that have been previously placed on a slope. Alternatively, the stakes can be tamped into place at the same time that rock is being placed on the slope face (USDA NRCS, 1996, p. 16–28). It is also referred to as rip-rap with live stakes.
- Live crib walls: A box-like interlocking arrangement of untreated log or timber members. The structure is filled with suitable backfill material and layers of live branch cuttings that root inside the crib structure and extend into the slope. Once the live cuttings root and become established, the subsequent vegetation gradually takes over the structural functions of the wood members (USDA NRCS, 1996, p. 16-25). See illustration in nature-based coastal techniques. See illustration in nature-based coastal techniques.
- Log, rootwad, tree and boulder revetment: A revetment is a facing of armoring material shaped to conform to and protect a shoreline (USDA NRCS, 1996, p. 16–87). These revetments are systems composed of logs, rootwads (a tree trunk or root mass), whole trees and boulders selectively embedded in and on banks (USDA NRCS, 1996, p.16–87) (Figure A.20-2). Whole trees are usually cabled together and anchored by earth anchors, which are buried in the bank. Each approach can provide excellent overhead cover, resting areas, shelters for insects and other fish food organisms, substrate for aquatic organisms and water velocity that results in sediment flushing and deeper pools (USDA NRSC, 1996, p. 16–36).
- Toe protection using fiber logs: Toe protection is material used to protect or armor the toe of a bank, where the slope meets the streambed (USDA NRCS, 1996, p. 16–88). Material can be fiber logs or rolls, stone or timber. A fiber roll is a coconut fiber (coir), straw or excelsior woven roll encased in netting of jute, nylon or burlap used to dissipate energy along bodies of water and provide a good medium for the introduction of vegetation. The roll is anchored into the bank and, after suitable backfill is placed behind the roll, herbaceous or woody vegetation can be planted. See illustration in nature-based coastal techniques.
- Vegetated geogrid – A vegetated geogrid is a system of successive soil lifts, or layers, wrapped in a synthetic or natural fiber material with live branch cuttings placed

between layers (Allen et al., 2006, modified from USDA NRCS, 1996) See illustration in nature-based coastal techniques.

Credit: NYS DEC.

Figure A.20-1. Dormant post plantings along a stream.



Credit: Virginia Department of Conservation Recreation.

Figure A.20-2. Diagram of design for root wad revetment, a practice that embeds tree trunks with roots to stabilize a bank.

Bed stabilization

These techniques foster the re-establishment of a stable cross-section of the stream channel. The design of bed stabilization structures requires expertise in stream shape (morphology) and flow (hydraulics).

Techniques:

- Native material transplants – Installation of native vegetation (i.e. seeding, live stakes, containerized shrubs and balled and burlapped trees) along stream banks helps to stabilize streambanks; provides overhead and in-water shade; and increases macroinvertebrate and fish habitat.
- Riffle pools and step pools - A riffle-pool sequence intersperses riffles, or shallow river reaches with a surface broken by rubble or small boulders, with deeper pools, which help to dissipate energy. Designs aim to maintain a balance between the ratio of the length of riffles to the length of the pools. In a step-pool sequence the flow velocity is dissipated through a series of pools that slow flow velocities. Step-pool sequences are typically found in areas of steeper slopes like headwaters and narrow valleys (Figure A.20-3) (Cornell Local Roads Program, n.d.).

Credit: Cornell Local Roads Program.

Figure A.20-3. Riffles and pools in the Butternut Creek in Butternut Creek in Otsego County.
Riffles can be seen breaking the surface of the water. A pool is at the bottom of the photo.

- J-hooks, vanes, cross-vanes - These techniques direct strong currents away from the bank and toward the thalweg (line of lowest stream elevation) and spread out energy in deep long pools (Figure A.20-4 and Figure A.20-5).
- Weirs – These approaches are designed to establish grade control in areas of stream migration. If designed properly they can reduce the risk of head cutting (erosion of the bed that can migrate upstream) and downcutting and provide spawning and holding cover for fish species (Rosgen, 1996).

There are many other nature-based stream design techniques. More examples can be found in (USDA, 2007), (McCullah and Gray, 2005) and (USDA NRCS Colorado, 2013).

Credit: NYS DEC.

Figure A.20-4. Use of log vanes (logs embedded in stream in v-shape) to stabilize a stream bed. The logs are placed such that the gap at apex directs downstream flow toward the center of the channel. Synthetic landscape cloth is visible on the upper log.

Credit: NYS DEC.

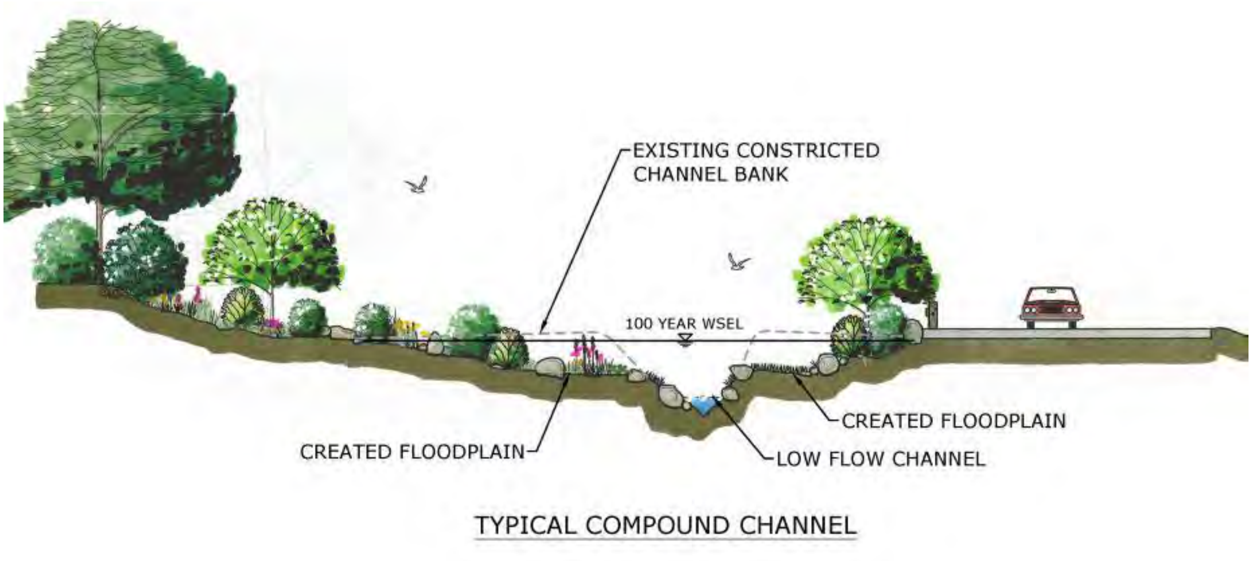
Figure A.20-5. Use of a rock vane to redirect water flow from a culvert and reduce erosion on the streambank.
Red arrow points to the rocks in the vane. Flow from the culvert is being directed by the vane to the right and then back to the left over the rock vane.

Floodplain reconnection

These techniques aim to reestablish connectivity between the waterbody and its floodplain. They may include removal of manmade flood protection such as berms, levees or dikes, removal of fill or reduction of impervious surfaces, including structures and pavement. Techniques may include revegetation, regrading of the slope in areas adjacent to the stream to allow more water to access the floodplain. It can also include stream corridor, wetland and riparian area restoration to stabilize floodplain erosion. It may be combined with constructed stormwater green infrastructure techniques on site or above the floodplain to capture and slowly release floodwaters.

Techniques:

- Revegetation of floodplain riparian areas or wetlands.
- Shaping, grading or contouring of the bank to allow more water to access the floodplain.
- Planned and controlled removal of flood protection structures to reconnect a stream or riverine shoreline to its floodplain can create large flood storage areas that also serve as significant wildlife habitat.
- Moving or siting levees or other flood protection structures back from the channel can allow streams and rivers to connect to some floodplain area while still providing flood protection to densely developed areas. Planting of native shrubs and grasses in these controlled floodplain areas can provide habitat value.
- Floodplain area can be created by excavating soil to offset the vertical difference between floodplain and flow levels, increasing water storage during high flows (Figure A.20-6). Vegetation and natural materials can be used to add habitat value to the new floodplain area. Constructed stormwater green infrastructure techniques may also be used to capture and slowly release stormwater.



Credit: Milone and MacBroom, Inc., 2014.

Figure A.20-6. Example design of excavated and revegetated floodplain.
The new floodplain area will store and absorb floodwaters. The more gradual slope will stabilize the stream bank.

Stream Daylighting

This technique uncovers previously-culverted or piped streams to reduce the velocity of runoff, increase water storage, promote infiltration of water into the ground and reduce pollutant loads (Figure A.20-7 and Figure A.20-8). It can also dramatically improve stream habitat.

Credit: NYS DEC.

Figure A.20-7. Saw Mill River in Yonkers, New York before stream daylighting. The stream is running under buildings and parking lots in a Yonkers business district.

Credit: NYS EFC.

Figure A.20-8. Daylighted Saw Mill River in Yonkers, NY.
Prior to this project the stream ran underground beneath parking lots in a business district.

How do nature-based stream techniques reduce risk?

Nature-based stream features should be designed to mimic or be enhanced by natural features and processes in stream, river, estuarine, lake or ocean coastal systems. The greatest risk reduction benefit is achieved when the larger natural system is conserved or maintained. Risk reduction will vary based on management of these individual features. Other measures may be needed to further reduce risk from large surge or flood events.

Below are examples of how nature-based stream techniques mimic the risk reduction benefits of natural features:

- **Serve as a barrier:** Techniques that stabilize banks attenuate currents and hold water in waterbodies until they are overtopped.
- **Reduce water velocity:** Structures that mimic stream bed friction, roughness and pools dissipate current and reduce stream velocity (Chemung County SWCD, 2006, p. 32). Reconnecting a stream to its floodplain improves storage, may lower flood elevations and reduce the flashiness of flows.

- **Absorb water:** Techniques that use shoreline vegetation allow roots to promote uptake of water by plants and infiltration of water running off the land into the ground before it reaches the stream.
- **Stabilize sediment:** Restoration of a stream's pattern, profile, dimension and vegetation to approximate historic or reference conditions (i.e. similar to stable reaches of the stream) can reduce bank erosion.
- **Provide conveyance:** Streams and rivers are confined drainage pathways within the floodplain and convey water downstream. Streams only mitigate the risk from flooding (elevation and extent) until the bank full stage, which is the flow at which water first overtops the banks onto the floodplain.

Forces and conditions that nature-based stream features can mitigate to reduce risks to people and communities

- Currents generally parallel to the shoreline causing damage from erosion, floating debris or the mobilization of ice.
- Precipitation or meltwater moving downhill to nearest waterbody causing erosion, temporary pooling and localized property damage
- Temporarily elevated water levels from surge, high river flows or high lake levels inland of the shoreline causing property damage

Human activities that reduce or impair risk-reduction capacity

- Strong boat wakes and vandalism may dislodge vegetation and structural components.
- Inadequate protection from grazing of domestic or wild animals can lead to vegetation loss.
- Incompatible adjacent land uses and poorly managed run-off from upland areas can increase erosion and destabilize a nature-based structure.
- Hard structural features in adjacent and nearby shoreline areas may interrupt sediment transport and increase water velocity increasing stress on the structure and adjacent banks.
- Undersized bridge and culvert openings in streams can cause flooding, deposit sediment and create barriers for aquatic organisms.
- A lack of proper maintenance of bank stabilization structures can lead to failure of of the structures and damage habitat.
- Major reductions in the upstream corridor (channel, banks, floodplain and riparian area) and removal of woody debris can increase water velocities increasing the potential for bank erosion.

- Large increases in runoff due to increases in paved or impervious surfaces in the watershed or loss of floodplain storage can lead to water levels that overwhelm nature-based stream techniques.
- In-stream dredging and realignment work that is not done in accordance with natural stream channel dynamics can impair the natural function of the stream and lead to erosion. Over-sizing of channels can create depositional zones that can increase flood extent.

Other benefits

Nature-based stream techniques provide a range of other benefits, including the following:

- **Economic:** Stable streams provide access for water-dependent uses, such as recreation and tourism. Nature-based techniques can reduce the negative effects of erosion management on downstream reaches. In contrast to many hard structural measures that increase water velocity and the risk and cost of downstream erosion, nature-based features incorporate vegetation, which stabilizes sediment and reduces water velocity downstream. Daylighting of streams in urban areas can have a positive effect on the economy and culture (*Saw Mill River Coalition*, n.d.).
- **Habitat:** Stream restoration techniques can provide habitat for fish, wildlife and macroinvertebrates.
- **Drought mitigation:** Properly restored rivers and streams have a low flow channel that provides for aquatic organism passage and refuge during dry periods.
- **Extreme heat mitigation:** Healthy stream and riverside vegetation provides shade to cool the stream. Vegetated natural areas can mitigate extreme heat and the urban heat island effect by providing shade and/or through the cooling effect of evapotranspiration, which releases water vapor (and heat energy) to the atmosphere. Minimal use of rock riprap along the stream bank can help to keep runoff flowing into streams cool, for fish and water quality. Use of proper width to depth ratios in a design helps avoid construction of over-widened channels with warm, shallow water.
- **Community, culture and recreation:** Communities value streamside areas for scenery and providing access for boating, fishing, swimming, hiking, hunting, trapping and bird watching. They are often closely coupled with communities' sense of place and local cultural traditions. Restoration of streams improves scenery and can provide a platform for recreational use by the public. Fishing opportunities typically increase as a result of a stable stream system that provides good fish and wildlife habitat.
- **Water filtration/quality:** The restoration of natural features of a stream (riffle, run, pool, glide sequence) allow areas for sediment to fall out of the water column and increase dissolved oxygen levels in the water. Vegetated banks, riparian areas and floodplains process and reduce nutrients.

➔ **Sequester carbon dioxide:** Vegetation sequesters carbon. Restored and nature-based streams increase both total carbon and free carbon sequestration in the banks and floodplains of restoration areas by increasing root biomass and tree canopy cover (Lewis et al., 2013).

Possible effects of changes in climate and water levels on nature-based stream techniques

Stronger storms

- Stronger storms and increases in impervious surfaces in watersheds will create higher flows. Structures and infrastructure in the floodplain will be at increased risk of flooding and erosion. If streams cannot dissipate energy in the stream channel or through access to the floodplain, they will erode and move in response to higher flows. The channel will continue to move and change until it can accommodate new flows and transport the new sediment load. Where hard structural features exist the stream channel will not be able to move and adjust to higher flows. This will result in higher water elevations and water velocity, creating larger flood events downstream. Modeling should be used to evaluate alternatives that account for these factors (Cramer, 2012).
- Strong storms may result in scouring and loss of vegetation, reducing bank and channel integrity and function, until vegetation is re-established. Regular maintenance and re-planting may be needed if a strong storm occurs before bank vegetation becomes established.

Warmer temperatures

- As the climate warms, certain invasive plants may dominate bank and riparian habitat, but fail to provide sufficient root structure to prevent soil erosion. This may increase the need for vegetation management.

Short-term drought

- Drought may increase the need for vegetation management along the streambank. If vegetation dies and is not replanted it will reduce stabilization of the bank.

Examples of locations where restored or nature-based stream techniques have been implemented

- Greene, Ulster, Sullivan and Delaware Counties: These counties have constructed an extensive set of multiple-objective stream restoration projects on the Schoharie, Esopus and headwater Delaware watersheds. These projects have employed a variety of best management practices and are documented at *www.catskillstreams.org* and *http://www.gcswcd.com/swp/stream-sw-projs/sc-projs*
- Sandy Creek Streambank Stabilization: Willow plantings and rock were used to control erosion and restore fish and wildlife habitat in the Sandy Creek's watershed.

http://www.healthylakes.org/successes/restoration-success-stories/stabilized-sandy-creek-riverbank-restores-fish-habitat-and-reduces-runoff/

Factors to consider in design, construction and maintenance for restoration (if a natural feature) or construction (if a nature-based feature)

- Aim to imitate the diversity of natural materials and structures on undeveloped shorelines adjacent to the site. Include natural buffer zones between manicured areas, such as lawns, and the shoreline.
- The use of all structures must be based on analysis of the stream's departure from stable reference conditions and justified by their ability to restore the reach to stable conditions.
- The grade or slope of a stream or river channel must be stabilized before bank stabilization, or other stream work can be effective. Any form of bank stabilization will only be temporarily effective if a stream is actively degrading its channel (Chemung County SWCD, 2006).
- Maintenance of a stable slope (longitudinal profile) adequate to transport sediment, yet not degrade or erode the bed may be addressed by adjusting stream alignment and, where necessary, with the use of stabilization structures.
- Protecting the alignment of a newly restored stream can be accomplished with the use of nature-based features in the short term and vegetation over the long term, especially on lower gradient reaches. Woody debris can help to reduce erosion.
- Upland stormwater drainage conditions are important to understand. Concentrated surface water runoff and seepage from the face of the bank can cause down-cutting or failure of the slope. Constructed stormwater green infrastructure techniques can be used to intercept stormwater to prevent it from flowing down the face of a bluff or slope.
- Designs should minimize the physical and ecological constraints placed on the stream. It is most important to allow for connectivity between the stream and the floodplain (Cramer, 2012).
- Designs should consider alternatives for near-term and long-term restoration that account for climate change (Cramer, 2012). Use of hydraulic models during the design process will provide information on how the restoration project will perform over a range of flows and help determine the most appropriate solution to withstand higher flows and associated sheer stress. Modeling using HEC-RAS or other hydraulic software is recommended to determine the effects of adjustments to floodplain elevation, changes in shear and water velocity, stream dimensions and bankfull width to depth ratio. The United States Geological Survey's free web-based program, Future Flow Explorer, also provides useful information.

- Nature-based stream reaches should be inspected and evaluated annually and after each significant storm event.
- Large woody debris reduce water velocity and play important ecological roles in streams and along natural and stabilized banks and should remain in place (Strayer and Findlay 2010).

Vegetation Considerations:

- Plantings should be nurtured and temporarily protected from erosion and grazing by domestic and wild animals until they are established.
- Typically, the eroded shoreline will need to be graded back prior to the installation of bioengineered approaches.
- If woody vegetation is being used, the seasonality of harvesting and installing plant cuttings should be considered (e.g. some cuttings should be installed during the plant's dormant season).
- Stabilization projects should be monitored regularly, and especially after extreme weather events and the winter season. Routine maintenance carried out including controlling invasive species and re-planting native species that fail to thrive.

Resources

There are many sources of engineering guidance for nature-based shoreline and stream bank stabilization including the U.S. Army Corps of Engineers, USDA Natural Resources Conservation Service and Soil and Water Conservation Districts. See Sources list for full citations for the following:

- Allen and Leech (1997)
- USDA NRCS (1996 and 2007)
- Allen et al. (2006)
- Rella and Miller (2012)
- NYS DEC guidance documents can be found at the links below:
  - *Shoreline Stabilization: Ecological Importance of Natural Shorelines and Proper Shoreline Stabilization*
  - *Shoreline Stabilization Techniques*
  - *Shoreline Stabilization – Interpretive Guidance to Staff*
  - *Sample Project Plans for Protection of Waters and Wetland Permit Applications*
  - *NYS DEC Post-Flood Stream Reconstruction Guidelines and Best Practices*
  - *Stream Crossings: Guidelines and Best Management Practices*

- *New York Standards and Specifications for Erosion and Sediment Control*

- County Soil and Water Conservation Districts can be a great resource for information, training and help when working in and around waterbodies. Find a complete list of county contacts on the New York State Soil and Water Conservation Committee's website: *https://www.nys-soilandwater.org/contacts/county_offices.html*
- United States Geological Survey (USGS) Future Flow Explorer can be used to estimate future flows under climate change: *https://ny.water.usgs.gov/maps/floodfreq-climate/* or search for FutureFlow Explorer at *https://www.nyclimatescience.org/*
- Consult with the appropriate regulatory agencies before designing any nature-based stream project.

Sources

1. Allen, H. H., & Leech, J. R. (1997). Bioengineering for Streambank Erosion Control: Report 1—Guidelines (Technical Report EL-97-8). Vicksburg, MS: U.S. Army Corps of Engineers Waterways Experiment Station.
2. American Rivers River Restoration Program. (2016). Reconnecting Rivers to Floodplains: Returning natural functions to restore rivers and benefit communities. Retrieved from *https://www.americanrivers.org/conservation-resource/reconnecting-floodplains/*
3. Catskill Streams. (n.d.). Retrieved from *www.catskillstreams.org*
4. Chemung County Soil & Water Conservation District (SWCD). (2006). Stream Processes: A Guide to Living in Harmony with Streams. Retrieved from *http://www.catskillstreams.org/pdfs/chemungstreamguide.pdf*
5. Cornell Local Roads Program. (n.d.). Emergency Stream Intervention. Retrieved from *http://www.clrp.cornell.edu/nuggets_and_nibbles/articles/2016/stream.html*
6. Cramer, M. L. (Ed.). (2012). Stream Habitat Restoration Guidelines. Olympia, WA: Washington Departments of Fish and Wildlife, Natural Resources, Transportation and Ecology, Washington State Recreation and Conservation Office, Puget Sound Partnership and the U.S. Fish and Wildlife Service.
7. Great Lakes Coalition. (2016). Stabilized Sandy Creek Riverbank Restores Fish Habitat and Reduces Runoff. Retrieved from *http://www.healthylakes.org/successes/restoration-success-stories/stabilized-sandy-creek-riverbank-restores-fish-habitat-and-reduces-runoff/*
8. Lake, D. W., Jr., and New York State Department of Environmental Conservation (NYS DEC). (2016). New York State Standards and Specifications for Erosion and Sediment Control (The Blue Book). Retrieved from *https://www.dec.ny.gov/chemical/29066.html*

9. Lewis, D. L., Lennox, M., O'Geen, A., Eviner, V., Larson, S., Harper, J., Doran, M., & Tate, K. (2013). Carbon Sequestration Trajectory: Soil Carbon Pools Following Stream Restoration. University of California Agriculture and Natural Resources. Retrieved from *http://ucanr.edu/sites/statewideconference2013/files/165845.pdf*

10. McCullah, J., & Gray, D. (2005). Environmentally Sensitive Channel- and Bank-Protection Measures (No. 544). Transportation Research Board. Retrieved from *http://www.trb.org/Publications/Blurbs/156479.aspx*

11. Milone and MacBroom, Inc. (2014). Emergency Transportation Infrastructure Recovery Water Basin Assessment and Flood Hazard Mitigation Alternatives. Mud Creek, Oneida County, NY. Retrieved from *https://wri.cals.cornell.edu/sites/wri.cals.cornell.edu/files/shared/documents/2014_Mud_Creek_Assessment.pdf*

12. National Technical Information Service (NTIS) Federal Interagency Stream Restoration Working Group. (1998). Stream Corridor Restoration – Principles, Processes and Practices. NTIS Order Number: PB98-158348. Retrieved from *http://www.usda.gov/stream_restoration*

13. New York State Department of Environmental Conservation (NYS DEC) Bureau of Habitat. (2006). Shoreline Protection Interpretive Guidance to Staff. Aquatic Habitat Protection Program. Retrieved from *http://www.dec.ny.gov/permits/6042.html*

14. New York State Department of Environmental Conservation (NYS DEC). (n.d.-b). Shoreline Stabilization: Ecological Importance of Natural Shorelines and Proper Shoreline Stabilization. Retrieved from *http://www.dec.ny.gov/docs/permits_ej_operations_pdf/shorestabil.pdf*

15. New York State Department of Environmental Conservation (NYS DEC). (n.d.-c). Sample Project Plans for Protection of Waters and Wetland Permit Applications. Retrieved from *http://www.dec.ny.gov/permits/70934.html*

16. New York State Department of Environmental Conservation (NYS DEC). (n.d.-d). Guidelines for Post-flood Stream Construction. Retrieved from *http://www.dec.ny.gov/docs/administration_pdf/postfloodguid.pdf*

17. New York State Department of Environmental Conservation (NYS DEC). (n.d.-e). Stream Crossings: Guidelines and Best Management Practices. Retrieved from *https://www.dec.ny.gov/docs/permits_ej_operations_pdf/streamcrossbmp.pdf*

18. New York State Department of Environmental Conservation (NYS DEC). (2010). Shoreline Stabilization Techniques. Retrieved from *http://www.dec.ny.gov/docs/permits_ej_operations_pdf/stabiltechguid.pdf*

19. New York State Department of Environmental Conservation (NYS DEC). (2012a). Bureau of Habitat DEC Guidelines for Post-Flood Stream Reconstruction. Retrieved from http://www.dec.ny.gov/docs/administration_pdf/postfloodguid.pdf

20. New York State Department of Environmental Conservation (NYS DEC). (2012b). Post-Flood Emergency Stream Intervention Training Manual. Retrieved from http://www.dec.ny.gov/docs/administration_pdf/streammnll.pdf

21. Rella, A., & Miller, J. (2012). Engineered Approaches for Limiting Erosion along Sheltered Shorelines. Stevens Institute of Technology, in association with and published by the Hudson River Sustainable Shorelines Project, Staatsburg, NY 12580. Retrieved from https://www.hrnerr.org

22. Rosgen, D. (1996). Applied River Morphology Second Edition. Pagosa Springs, CO: Wildland Hydrology.

23. Saw Mill River Coalition. (n.d.). Daylighting the Saw Mill River in Yonkers. Retrieved from http://www.sawmillrivercoalition.org

24. Strayer, D.L., & Findlay, S.E.G. (2010). The Ecology of Freshwater Shore Zones. Aquatic Sciences, 72: 127–163.

25. U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). (1996). Part 650 Engineering Field Handbook, Chapter 16 Streambank and Shoreline Protection. Aberdeen, ID. Retrieved from http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17553.wba.

26. U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). (2007). Part 654 Stream Restoration Design National Engineering Handbook, Chapter 11: Rosgen Geomorphic Channel Design (Report No. 210–VI–NEH). Retrieved from http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/water/manage/restoration/?cid=stelprdb1044707

27. U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Colorado. (2013). Guidance for Stream Restoration, Technical Notes (Engineering CO-TN-ENG-27.2) Retrieved from http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_062267.pdf

Appendix B: Natural features and processes in upland, riverine and coastal areas

Flooding and erosion are natural processes. Large flood events raise the elevation of waterbodies, leading them to overtop their banks. This flooding replenishes nutrients to valley soils, disperses seeds, builds beaches and supports wetland habitats. Erosion is the transport of soil, rock and dissolved material from one location to another through runoff, currents, wind and waves. This natural process supports features like inlets, beaches and shoals in coastal areas and builds wetlands in bays and at the mouths of rivers and streams. In fact, research suggests that flooding and erosion is essential for sustaining some natural features and biological communities (Florsheim et al., 2008; W.F. Baird and Associates, 2011; Roberts, 2012).

Natural features that reduce flood and erosion risk may appear static relative to the landscape, but they are dynamic and are affected by a variety of natural physical, geological, biological and chemical processes.[35] Understanding these processes is essential to conserving the risk-reduction services natural systems provide now and in the future.

Development frequently encroaches on natural features, constraining their ability to respond to the energy of waves and currents and absorb and store water. This can reduce or eliminate the storm buffering capacity of natural features and increase risk to public and private assets.

Natural features are more effective at reducing risk when they are part of a larger system that hasn't been degraded. For example, when wetlands in the floodplain and throughout the watershed are able to store water, downstream flood risk is reduced (Novitski, 1982).

To illustrate these concepts the following sections summarize how natural features and processes form systems that respond to flooding and reduce risk in upland, stream/riverine and coastal (lake, estuarine and ocean) environments. Underlined text indicates natural features with Feature Descriptions (Appendix A). More information on the features and processes discussed below and literature references can be found in the Feature Descriptions.

[35] Landscape features that provide valuable services may also be known as natural green infrastructure.

Upland systems and natural processes

Upland areas consist of many watersheds. A watershed is the area of land that drains downhill, either over land or underground, into a specific stream or waterbody (e.g., wetland, pond, lake, stream, river, estuary or ocean). Watersheds are divided by high points on the land such as ridges, mountains or hills. from which water from precipitation flows, either overland or underground, downhill to a receiving waterbody (e.g., wetland, pond, lake, stream, river, estuary or ocean) (Figure B-1).

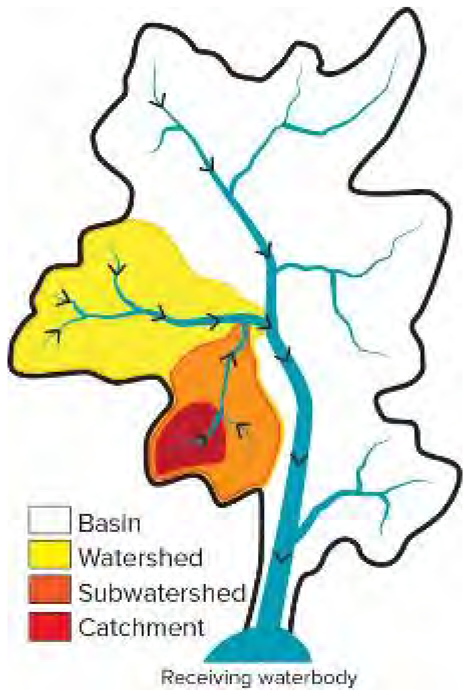
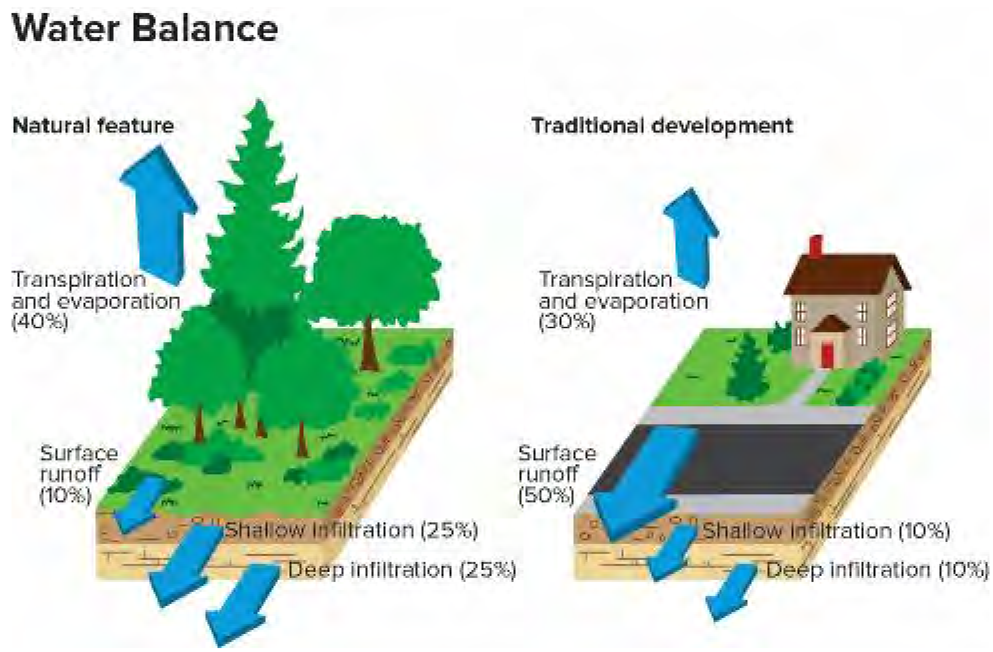


Figure B-1. An illustration of nested watersheds in a riverine system. The terms "catchment," "sub-watershed" and "watershed" may be used interchangeably.
Catchments and sub-watersheds typically refer to relatively smaller watersheds that drain into larger watersheds. The term "basin" typically refers to a larger watershed, that encompasses all the streams in a watershed system.

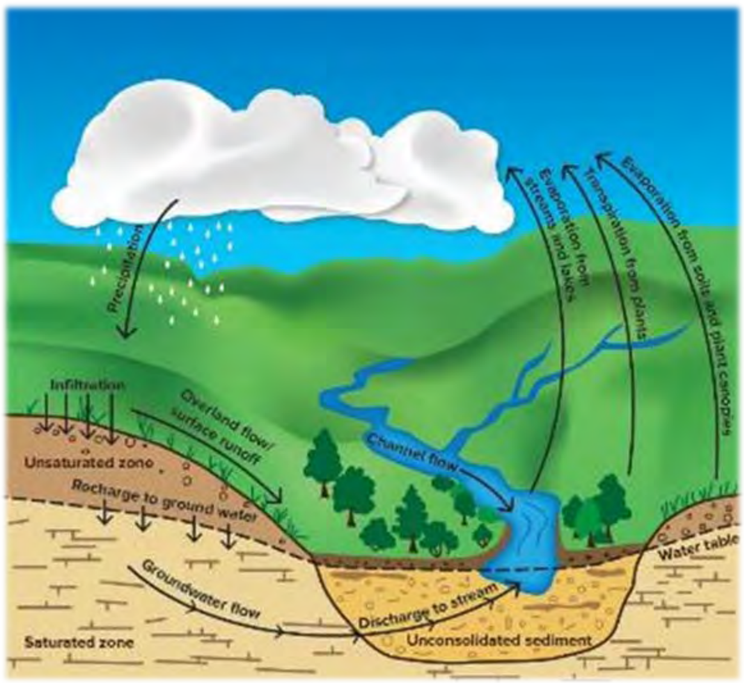
Overland flow or surface runoff occurs when water from rain or snowmelt in a watershed flows over saturated soils, paved surfaces or dense soils and cannot percolate into the ground (Figure B-2). Instead runoff flows overland to a receiving waterbody. Surface runoff carries soil and sediments and can also transport pollutants and trash. Very high flows can cause flooding and severe erosion.



Credit: Adapted from Schueler (1987).

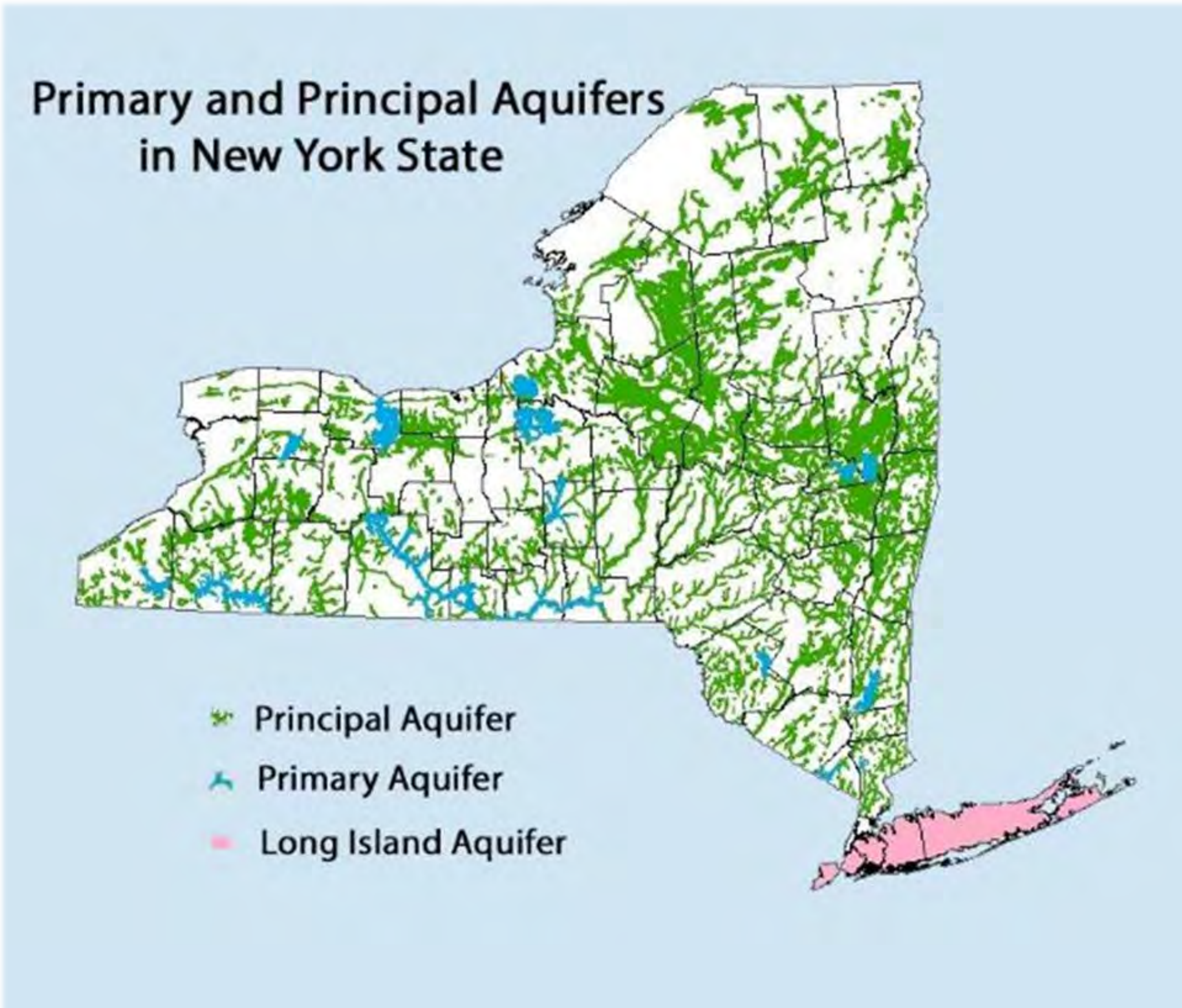
Figure B-2. When precipitation falls on a landscape, the water may evaporate/transpire, infiltrate or form surface stormwater runoff. Traditional development increases the amount of paved or impervious surfaces; this significantly increases the amount of runoff and decreases the amount of water that infiltrates into groundwater. Note that the percentages within this figure are representative values that are intended for illustrative purposes only.

Ground water is rain or snowmelt that soaks into the land and percolates or infiltrates downward into open spaces between soil particles or in cracks in rocks (Figure B-3). Ground water often collects in larger aquifers (Figure B-4). Infiltration rates can vary depending on many factors, such as the porosity of the soil or the level of saturation (e.g., prior wetness) and the presence or absence of vegetation. Ground water helps to maintain water, or baseflow, in streams, freshwater wetlands, lakes and other waterbodies between precipitation events or during drought conditions. It also is an important source of drinking water across New York State and the sole source of drinking water on Long Island.



Credit: Adapted from Kansas Geological Survey.

Figure B-3. Conceptual model of the watershed and water cycle. In a storm, some water or runoff, moves over land to the waterbody (stream). Large volumes of surface runoff will cause the waterbody to flood. Runoff can erode the land, sending sediment to the water body. Vegetation can slow and absorb water, reducing erosion. Some water infiltrates, or drains, into the ground through the soil (unsaturated zone) and eventually to the water table (saturated zone). It then slowly discharges to the stream or other waterbody.



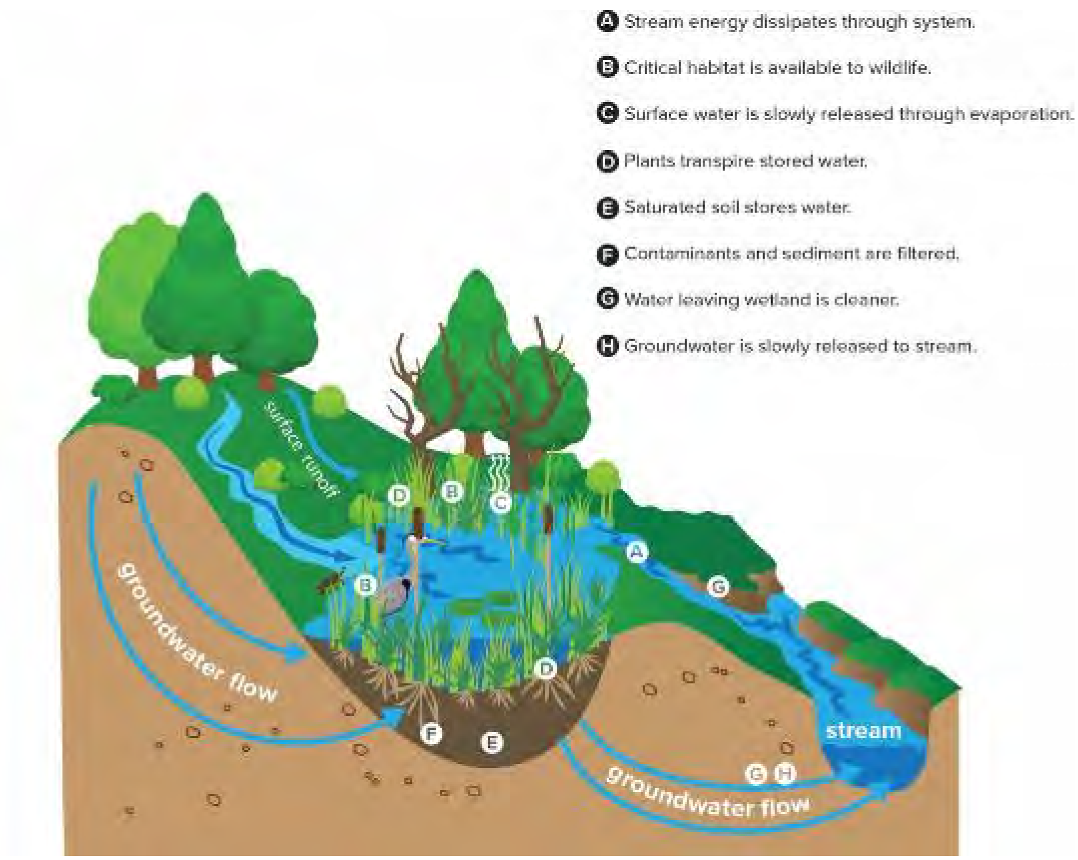
Credit: NYS DEC.

Figure B-4. Groundwater collects in larger aquifers.
Principal and primary aquifers in New York State are used for municipal water supply. All of Long Island is underlain by one or more productive aquifers, however, Long Island does not have any aquifers officially designated as “Primary” or “Principal” by New York State.

Forests play an important role in both surface and groundwater processes in watersheds. A large proportion of rainfall is intercepted by forest vegetation, and absorbed and stored in root systems, or evaporated back to the atmosphere. Vegetation also creates roughness along the ground that slows surface runoff and wind, thereby reducing erosion.

Wetlands intercept, store and filter water as it flows across the landscape. Similar to sponges, wetlands capture runoff and slowly release it, reducing peak flood elevations downstream (Figure B-5).

Floodplains and wetlands are exceptionally important to reducing flood damage because of their ability to spread out, slow and retain floodwater.



Credit: Adapted from Turner et al. (2005).

Figure B-5. Wetlands are hydrologically connected to the surrounding watershed through surface and groundwater.
In addition to slowing and storing floodwaters, they perform many important functions, including removing and recycling nutrients and sediment and filtering and breaking down contaminants.

Conservation of wetlands, forests and buffer areas between wetlands and development preserves their capacity to store floodwaters, replenish groundwater and provide other valuable services. Vegetated buffer areas can also naturally pre-treat stormwater runoff before it reaches delicate wetland ecosystems. As storms become more extreme, wetlands will need space to expand and contract, storing and releasing floodwaters between storms. In more developed areas, nature-based features can be used to mimic the functions of natural wetlands and forests. Use of constructed stormwater green infrastructure can increase water storage and groundwater infiltration in areas with existing development. For more information, see natural feature descriptions and Constructed Stormwater Green Infrastructure Techniques in Appendix A.

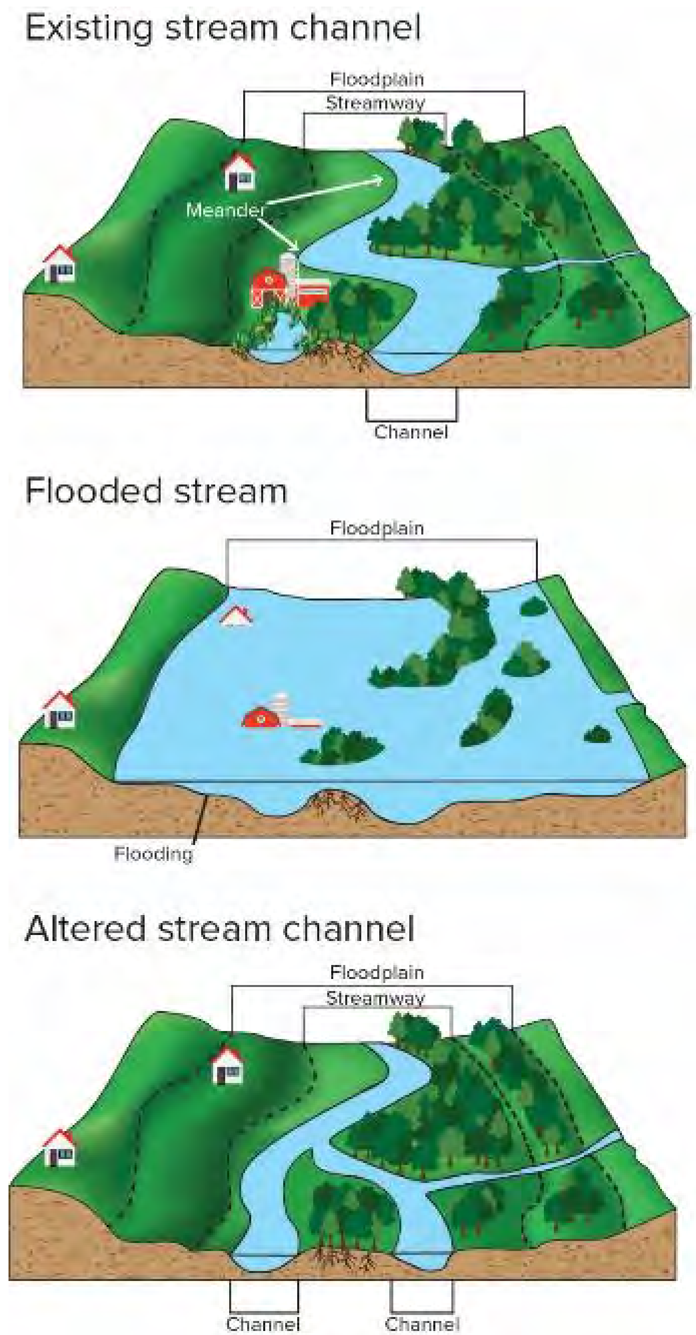
Stream/riverine systems

Streams convey water from the land and carry it downstream to larger rivers and eventually to the sea. [36] Streams have a variety of shapes and sizes depending on the amount of water they carry, geology, slope and land cover in the watershed. They naturally move across the landscape to accommodate changes in water and sediment flows. Figure B-6 illustrates the parts of a stream (channel, streamway, floodplain and meanders) and how they may be affected in a flood.

The channel is made up of the bed and banks. The streamway is the area adjacent to the channel that provides space for the channel to migrate over time and allows for natural dynamic changes in width, depth, slope and channel meander pattern as the stream responds to changes in flow and sediment.[37] Floodplains are low-lying areas adjacent to waterbodies that become inundated when the waterbody overflows during heavy rainfall or snowmelt. The Federal Emergency Management Agency (FEMA) evaluates the potential for flooding to determine the area of the floodplain regulated under the National Flood Insurance Program (FEMA, 2018). Meanders are the sinuous bends in a watercourse or river that form as a result of natural erosion and deposition of sediment.

[36] This section uses the term “watercourse” to refer to streams, rivers, and other drainage systems. When only “stream” is referred to, it is meant to be used in a broad sense of flowing waters and includes all streams and rivers.

[37] Explanations of stream dynamics and illustrative images can be found at FISRWG (1998), NYS DEC (2014), and Ohio State University Extension (2008).

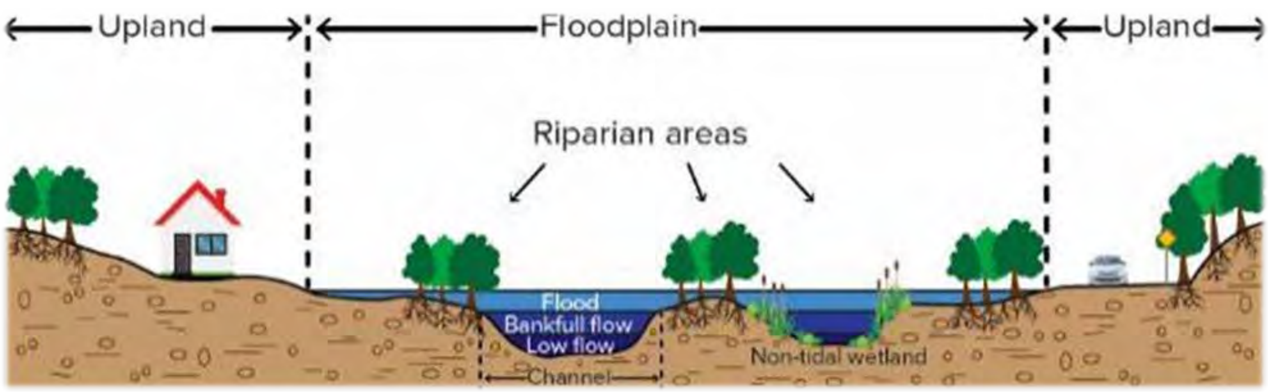


Credit: NYS DEC.

Figure B-6. This set of illustrations show the stream channel, floodplain, meander and streamway and how they can change during a flood. The middle diagram illustrates how water fills the floodplain during a flood. In flood conditions, the stream can move within the streamway and damage structures sited too close to the stream. The bottom diagram illustrates how the stream channel has split and moved as a result of the flood.

Gradual channel migration over time is a natural stream response to storm events, sediment movement and vegetation change. The rate of channel migration depends on flow and the geology and slope of the watershed. Dramatic channel erosion and change can occur in large storms, particularly in more developed watersheds where natural features that store water, like floodplains and wetlands, have been lost and shorelines have been hardened.

Riparian areas have high levels of soil moisture, flood frequently and are inhabited by plants and animals that are adapted to wet conditions. The riparian area is a transition zone between aquatic and upland areas, and the boundary may not be well-defined (Figure B-7). During high water events, vegetation in riparian areas can decrease water velocity and sediment erosion and deposition.



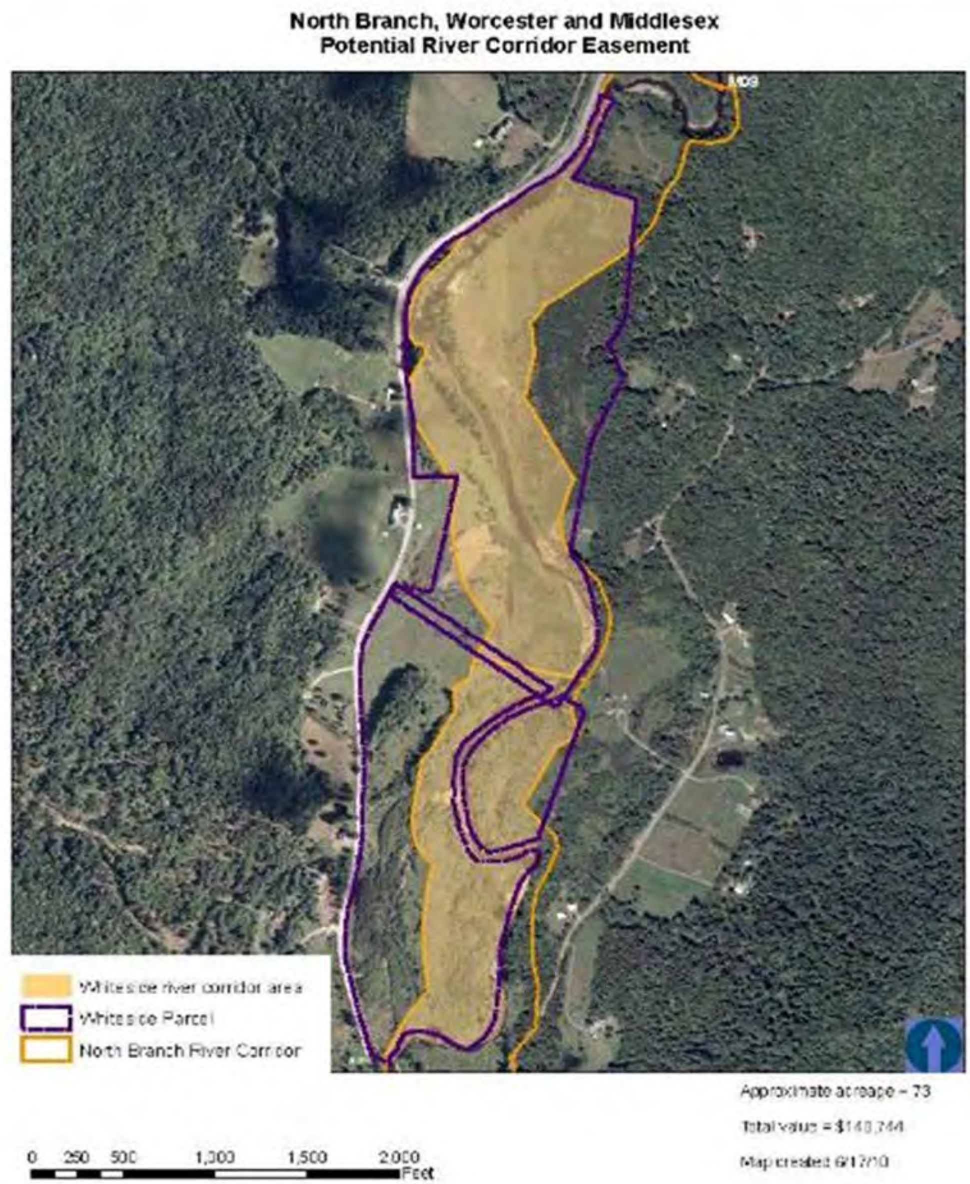
Credit: NYS DEC.

Figure B-7. Cross-section of a floodplain and riparian areas.
Water elevations in the stream channel often correspond with water levels in riparian areas, such as wetlands and forests during low and bankfull flows. During flood conditions the floodplain, wetlands and riparian areas slow and store water and their vegetation slows water velocity. During low flow conditions wetlands and riparian areas release water back to the stream sustaining aquatic plants and animals.

Conserving and protecting floodplains and revegetating banks and riparian areas slows and stores water on the landscape (Figure B-8). Keeping development outside the streamway and floodplain is the preferred way to reduce erosion and flood risk to people and property (Figure B-9). It allows these areas to absorb energy and water from high flows. It also ensures that if flooding and erosion do occur people and property will be safer. Where erosion protection is needed for existing development, restored or nature-based coastal measures should be considered. More information can be found in the natural feature descriptions and Nature-based Stream/Riverine Techniques and Constructed Stormwater Green Infrastructure (Appendix A).

Credit: NYS DEC.

Figure B-8. Volunteers from the Quassaick Creek Watershed Alliance and Preserve Algonquin Park partnered with DEC's Trees for Tribs Program to plant 160 native trees and shrubs to restore riparian areas along the Quassaick Creek in Cronomer/Algonquin Park in Newburgh, NY.



Credit: VT Department of Environmental Conservation.

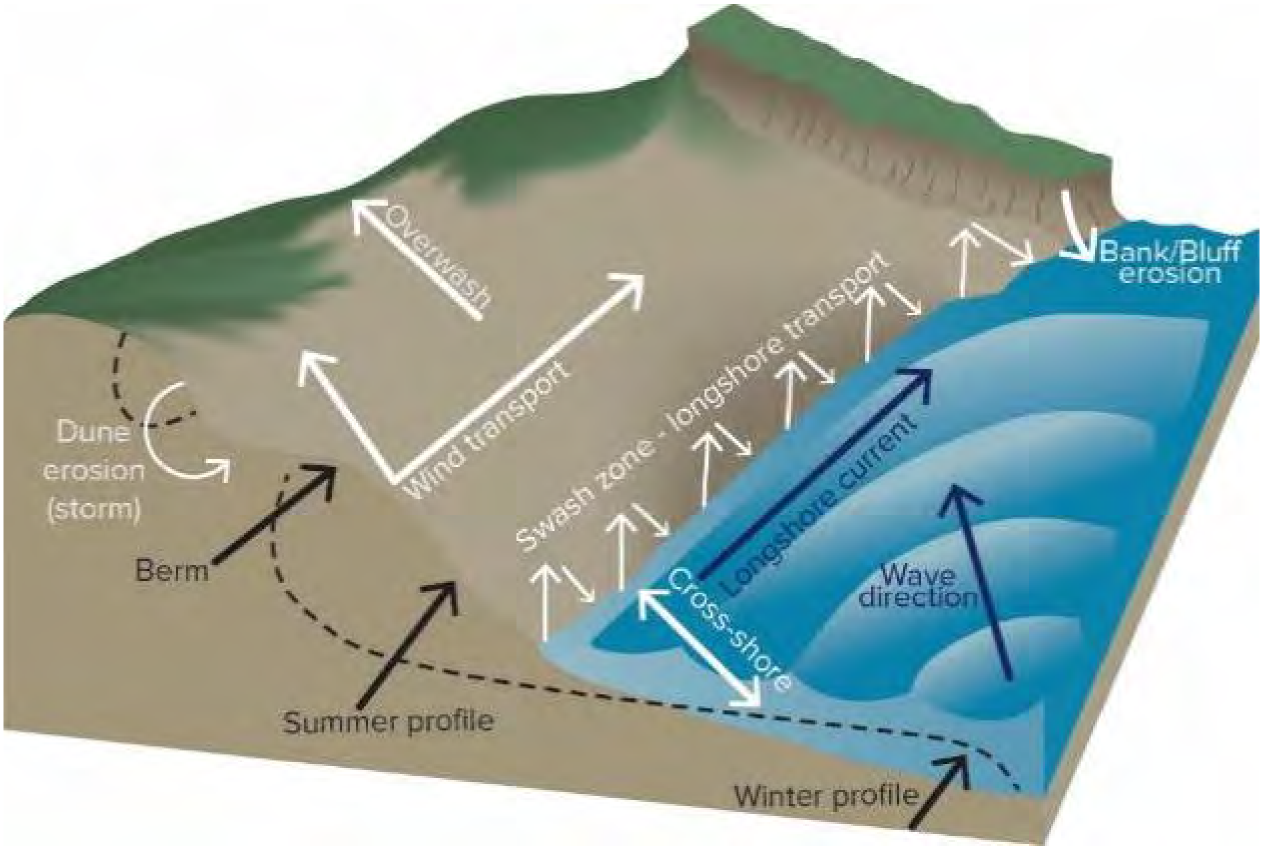
Figure B-9. Vermont has seen risk reduction benefits from using conservation easements to protect and preserve floodplains and riparian areas. This graphic illustrates an area within the floodplain of the North Branch of the Winooski River conserved under Vermont's River Corridor Easement Program. **Under the program, a landowner can sell their river channel management rights within the river corridor of sensitive and erosive streams. The yellow shaded area represents the new easement area within the North Branch River Corridor. Upon selling the channel management rights, the landowner can continue agriculture and silviculture, but is restricted from building new structures or erosion management measures within the easement area.**

Coastal systems and processes

Ocean, estuarine and lake systems are subject to the interplay between wind, waves, currents, sediment availability, gravity and the motion of the earth. Offshore currents move water and suspended sediment from one location to another. Closer to shore, wind action generates waves which in turn transport sediment onto or away from the shore (e.g., building or diminishing a beach).

Lake shorelines are subject to waves, storms and sediment transport, but not tides. Lake surges or seiches can occur due to strong winds and rapid changes in atmospheric pressure. Ice formation and movement are also prevalent on lake and estuarine systems in New York which may contribute to erosion through scour and sediment transport, or provide protective cover against erosive winter waves.

Natural features in coastal areas, like dunes, shoals or bars and beaches, can help to reduce the energy of waves and currents. The physical shape and size of colonized shellfish reefs above the bottom causes waves to break earlier, reducing wave energy. Submerged aquatic vegetation, or SAV, provides similar bottom surface roughness or friction, which can slow down wave energy. Depending on height and density of the vegetation, SAV may also dampen wave height. SAV roots also help stabilize bottom sediment, thereby reducing potential erosion. Tidal wetlands provide similar services by attenuating wave height and stabilizing sediment along the shoreline. Tidal wetlands may also have the ability to attenuate storm surge and flood elevation depending on the density and height of the vegetation and the size of the wetland. Some flood waters may also be stored or absorbed by a wetland system.



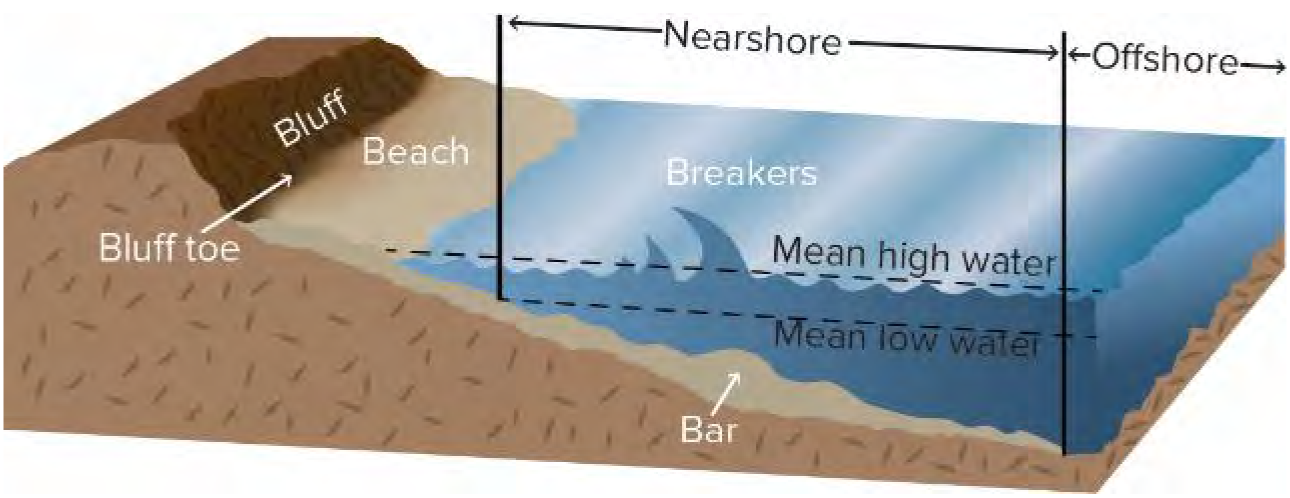
Adapted from: Greg Berman, Woods Hole Oceanographic Institution Sea Grant & Cape Cod Cooperative Extension.

Figure B-10. Sediment moves along the shoreline and off and onshore due to wave, current and wind action.
Sediment movement is indicated by white arrows and water movement is indicated by blue arrows.

Many natural features in coastal systems depend on adequate sediment and sand supply (Figure B-10) to provide their risk reduction and other co-benefits. Like stream and river processes, water moving on coastal shorelines transports sediment from one area to another. Wind also moves and shapes coastal features. Sediment moves both along (longshore) and across (cross-shore) the coastal shoreline through a variety of mechanisms:

- Sand and sediment increase on beaches when fair weather conditions and smaller waves transport sediment onshore, often during the summer. This deposition of sand can form a berm parallel to the shoreline. Adjacent areas can also contribute sediment through longshore transport. Beaches are eroded when steep waves transport sediment offshore, often in winter. When fair weather conditions return, waves may transport offshore sediment back onshore again.

- During storm events, waves tend to transport more sediment offshore, some of which may collect in the shallow nearshore or offshore area as a sand bar or shoal (Figure B-11).
- Prevailing winds move sediment down the beach. Wind-driven sediment can collect in vegetation behind a beach, forming dunes. Without stabilizing vegetation, dunes are susceptible to wind erosion (Figure B-10).
- Bluffs naturally erode due to wind, waves or runoff providing a critical source of sediment for beaches, (Figure B-10).
- Barrier islands form in the ocean where enough sand or gravel is deposited by wave action to enclose a bay. In a natural barrier island system, large waves and surge, carrying sediment, may build dune volume or deposit sediment behind the dune, widening the barrier. This is called an overwash.
- An inlet or breach can form as a result of a storm cutting through land, like a barrier island, or due to elevated water levels inside an embayment pushing outward through a barrier into an external waterbody. The inlet allows water and sediment to flow freely between two water bodies. Sediment movement through inlets can build up features like tidal wetlands.
- Maritime forests are sustained where they are protected from wind by dunes with sufficient sand supplies.



Credit: Adapted from US Navy.

Figure B-11. Cross-section of common features in the coastal onshore and nearshore area. The erosion of bluffs is an important source of sediment for beaches. Adequate sediment on beaches can reduce erosion at the bluff toe. Sediment deposited in nearshore and offshore areas by currents and waves can create bars and shoals that reduce wave height and velocity.

Coastal floodplains, tidal wetlands, barrier islands and other features can help to reduce coastal risk. Siting development and infrastructure away from natural coastal features is preferred because it gives these features room to absorb energy and water from storm events. It also ensures that if flooding and erosion do occur people and property will be safer. Where erosion protection is needed for existing development, restored or nature-based coastal measures should be considered. A variety of approaches that incorporate vegetation can be used in low- to moderate-energy coastal environments. In higher energy areas, dune and beach restoration can provide risk-reduction, habitat and recreational benefits. For more information, see the feature descriptions (Appendix A).

Sources

1. Federal Emergency Management Agency (FEMA). (2018). The National Flood Insurance Program. *https://www.fema.gov/national-flood-insurance-program*

2. Federal Interagency Stream Restoration Working Group (FISRWG) (1998). Stream Corridor Restoration: Principles, Processes, and Practices. Retrieved from: *http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044574.pdf*

3. Florsheim, J. L., Mount, J. F., & Chin, A. (2008). Bank Erosion as a Desirable Attribute of Rivers. Bioscience, 58(6): 519–529.

4. New York State Department of Environmental Conservation (NYS DEC). (2014). Post-Flood Emergency Stream Intervention Training Manual. Retrieved from *http://www.dec.ny.gov/docs/administration_pdf/streammnll.pdf*

5. Novitski, R. P. (1982). Hydrology of Wisconsin Wetlands. Wisconsin Geological and Natural History Survey Information Circular 40.

6. Ohio State University Extension. (2008.) Floodplains and Streamway Setbacks. Retrieved from *https://www.researchgate.net/publication/266874338_Floodplains_and_Streamway_Setbacks*

7. Roberts, T. (2012). Natural and Anthropogenic Influences on the Morphodynamics of Sandy and Mixed Sand and Gravel Beaches (Doctoral dissertation, p. 20). University of South Florida. Retrieved from *https://scholarcommons.usf.edu/etd/4216/*

8. Schueler, T. (1987). Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Prepared for Metropolitan Washington Council of Governments. Washington, D.C.

9. Turner, B., Franklin, R., Journeay, M., Hocking, D., Franc de Ferrier, A., Chollat, A., Dunster, J., Whitehead, A., & Blair-Whitehead, D. G. (2005). Waterscape: Bowen Island. Geological Survey of Canada. Miscellaneous Report 88. Retrieved from *https://auma.ca*

10. W. F. Baird and Associates. (2011). Lake Ontario Ecological Sediment Budget. Prepared for the U.S. Army Corps of Engineers Buffalo District.

Appendix C: Public co-benefits and services of natural resilience measures

Natural features and processes and nature-based features provide more environmental co-benefits for the public than hard structural measures. In addition to reducing risk from flooding and erosion, they add value by providing services such as contributing raw goods and materials, plant and animal habitat, water and air quality regulation, carbon sequestration, nutrient cycling and opportunities for tourism, recreation, education and research (Sutton-Grier et al., 2015; DiNapoli, 2010; Liu et al., 2010). The feature descriptions in Appendix A give more detail and examples of the co-benefits provided by each natural feature.

The value of these services often unrecognized because they are difficult to quantify and monetize (National Science and Technology Council, 2015). However, estimation methods do exist. Public co-benefits should be maximized in the design of risk management strategies. Loss of these public benefits should also be included in the estimated cost of development decisions.

Healthy natural features and processes provide more environmental co-benefits than nature-based features. This is because they are fully integrated into the surrounding natural system. However, nature-based features mimic natural systems and typically provide more environmental co-benefits than hard structural solutions alone.

- *Economic benefits*: These are the cost-savings or revenue a healthy functioning natural feature or process can provide to a community. Below are examples of how the added value of environmental co-benefits can increase the overall value of a nature-based approach.
  - The New York City Department of Environmental Protection has used healthy forests to lower drinking water treatment costs (NYC DEP, n.d.).
  - The production of goods (like wood products or fish), tourism and recreation can provide direct revenues. The forest products industry in New York State contributed over $9.9 billion dollars to the economy in 2012 (North East State Foresters Association, 2013). Parks and Trails New York estimated that the 55.7 million annual visitors to the New York State Park System generated $1.9 billion in economic activity (Heintz et al., 2009).
  - A recent analysis by New York City found that nature-based features such as green roofs and bioswales could help meet water quality goals with savings of more than $1 billion compared to conventional hard infrastructure (PlaNYC, 2011).
  - It’s been estimated that nitrogen loading could be reduced in the Chesapeake Bay by using cover crops at less than half the cost of upgrading wastewater plants (Chesapeake Bay Commission, 2004).

- Using a system of wetlands in North Carolina, the USACE calculated it could minimize stormwater runoff for $0.47 per thousand gallons treated, which is significantly less than conventional stormwater controls, which cost $3.24 per thousand gallons (USACE, 2001).

- *Habitat*: Habitat benefits are food, water and shelter necessary to sustain an organism. Natural and nature-based features provide habitat for plants and animals. For example, the aquatic area in front of hard structural measures such as seawalls and bulkheads is far less productive fish and invertebrate habitat than a gently sloping bank or wetland (Kornis et al., 2017; Strayer et al., 2012).
- *Drought mitigation*: Drought mitigation will become increasingly important as patterns of snow and rainfall change due to climate change. Natural features, like wetlands and forests, absorb and store water on the landscape and slowly release it during dry periods, naturally replenishing streams and groundwater wells (Mitsch and Gosselink, 1986).
- *Extreme heat mitigation*: Extreme heat mitigation is the reduction in intensity of exceptionally high temperatures and humidity. Forests and other dense vegetation moderate heat by providing shade and/or through the cooling effect of evapotranspiration, which releases water vapor (and thus heat energy) to the atmosphere. This is particularly important in urban areas where impervious surfaces including roofs and pavement produce a “heat island” effect, raising temperatures as much as 10 degrees higher than in surrounding areas (EPA, 2016).
- *Community, culture and recreation*: These are nonmaterial benefits such as public access to natural areas and use of nature in folklore, national symbols and heritage. Natural features, such as large natural beaches, dunes and bluffs, add to the value and identity of a community. Natural and nature-based features can provide the opportunity for public access to the shoreline and water, while vertical hard structural measures like bulkheads and seawalls will limit public access as sea levels rise.
- *Water quality*: Water quality can be improved by the physical capture of sediments and pollutants and by chemical and biological processes. Wetlands can trap impurities in sediment and transform excess nitrate into other less harmful forms through denitrification (Velinsky et al., 2013). Healthy forests stabilize slopes and minimize on-site erosion, reduce sediment entering water bodies. They also trap, filter, absorb or convert excess nutrients and other water pollutants as runoff infiltrates the soil. Water filtered through forested open space is less likely to pollute groundwater than hard structural stormwater measures like concrete retention basins (DiNapoli, 2010).
- *Water storage*: Water storage in surface and groundwater systems is important for drought mitigation, healthy streams and drinking water. Undeveloped floodplains, wetlands and riparian areas allow for the temporary storage of floodwaters, infiltration of water into the soil and support streams in dry periods.

- *Carbon capture and sequestration*: Oceans, vegetation and soils can sequester, or trap, carbon through chemical, physical or biological processes (Davis et al., 2015; NOAA, n.d.). The sequestration of carbon from carbon dioxide in the atmosphere by vegetation is important to slow and reduce the effects of climate change. Atmospheric carbon dioxide is taken up by vegetation through photosynthesis and stored as carbon in biomass. In 2015, EPA estimated that the value of damages avoided for a small emissions reduction was $36/ton CO_2 (EPA, 2015). This means a mature forest which sequesters about 15 tons of CO_2 would save approximately $540/acre.

Sources

1. Chesapeake Bay Commission. (2004). Cost-Effective Strategies for the Bay: Smart Investments for Nutrient and Sediment Reduction. Annapolis, MD. Retrieved from *www.chesbay.us/Publications/cost%20effective.pdf*

2. Davis, J. L., Currin, C. A., O'Brien, C., Raffenburg, C., & Davis, A. (2015). Living Shorelines: Coastal Resilience with a Blue Carbon Benefit. *PloS one*, 10(11): e0142595.

3. DiNapoli, T. (2010). Economic Benefits of Open Space Preservation. Office of the State Comptroller. Retrieved from *https://www.osc.state.ny.us/reports/environmental/openspacepreserv10.pdf*

4. Heintz, J., Pollin, R., & Garret-Peltier, H. (2009). The New York State Park System: An Economic Asset to the Empire State. Parks and Trails New York. Retrieved from *www.ptny.org/pdfs/advocacy/peri_full_report.pdf*

5. Kornis, M. S., Breitburg, D., Balouskus, R., Bilkovic, D. M., Davias, L. A., Giordano, S., Heggie, K., Hines, A. H., Jacobs, J. M., Jordan, T. E., King, R.S ., Patrick, C. J., Seitz, R. D., Soulen, H., Targett, T. E., Weller, D. E., Whigham, D. F., Uphoff, J., Jr. (2017). Linking the Abundance of Estuarine Fish and Crustaceans in Nearshore Waters to Shoreline Hardening and Land Cover. *Estuaries and Coasts*, 40(5): 1464–1486. Retrieved from *https://link.springer.com/article/10.1007/s12237-017-0213-6*

6. Liu, S., Costanza, R., Farber, S. and Troy, A. (2010). Valuing Ecosystem Services. Ecological Economics Reviews, 1185:54-78.

7. Mitsch, W. J., & Gosselink, J. G. (1986). *Wetlands*. New York, NY: Van Nostrand Reinhold.

8. National Oceanic and Atmospheric Administration (NOAA). (n.d.). Habitat Conservation: Coastal Blue Carbon. Retrieved from *http://www.habitat.noaa.gov/coastalbluecarbon.html*

9. National Science and Technology Council. (2015). Ecosystem-Service Assessment: Research Needs for Coastal Green Infrastructure. Committee on Environmental, Natural Resources, and Sustainability. Retrieved from

https://www.whitehouse.gov/sites/default/files/microsites/ostp/cgies_research_agenda_final_082515.pdf

10. New York City Department of Environmental Protection (NYC DEP). (n.d.). Forest Management. Retrieved from www.nyc.gov/html/dep/html/watershed_protection/forest_management.shtml

11. North East State Foresters Association. (2013). The Economic Importance of New York's Forest-Based Economy. Retrieved from http://www.dec.ny.gov/docs/lands_forests_pdf/economicimportance2013.pdf

12. PlanNYC. (2011). NYC Green Infrastructure Plan: A Sustainability Strategy for Clean Waterways. New York, NY. Retrieved from www.nyc.gov/html/dep/pdf/green_infrastructure/NYCGreenInfrastructurePlan_LowRes.pdf

13. Strayer, D. L., Findlay, S. E. G., Miller, D., Malcolm, H. M., Fischer, D. T., & Coote, T. (2012). Biodiversity in Hudson River Shore Zones: Influence of Shoreline Type and Physical Structure. *Aquatic Sciences*, 74: 597–610.

14. Sutton-Grier, A.E., Wowka, K., & Bamford, H. (2015). Future of Our Coasts: The Potential for Natural and Hybrid Infrastructure to Enhance the Resilience of Our Coastal Communities, Economies and Ecosystems. *Environmental Science & Policy*, 51: 137–148.

15. U.S. Army Corps of Engineers (USACE). (2001). Applicability of Constructed Wetlands for Army Installations. Public Works Technical Bulletin 200-1-21. Washington, D.C.

16. U.S. Environmental Protection Agency (EPA). (2015). Social Cost of Carbon. Fact Sheet.

17. U.S. Environmental Protection Agency (EPA). (2016). Using Trees and Vegetation to Reduce Heat Islands. Retrieved from https://www.epa.gov/heat-islands/using-trees-and-vegetation-reduce-heat-islands

18. Velinsky, D., Quirk, T., Peihler, M., & Smyth, A. (2013). Ecosystem Services of Tidal Wetlands in Barnegat Bay: Nitrogen Removal. Patrick Center for Environmental Research, Report 13-06. Drexel University Academy of Natural Sciences.

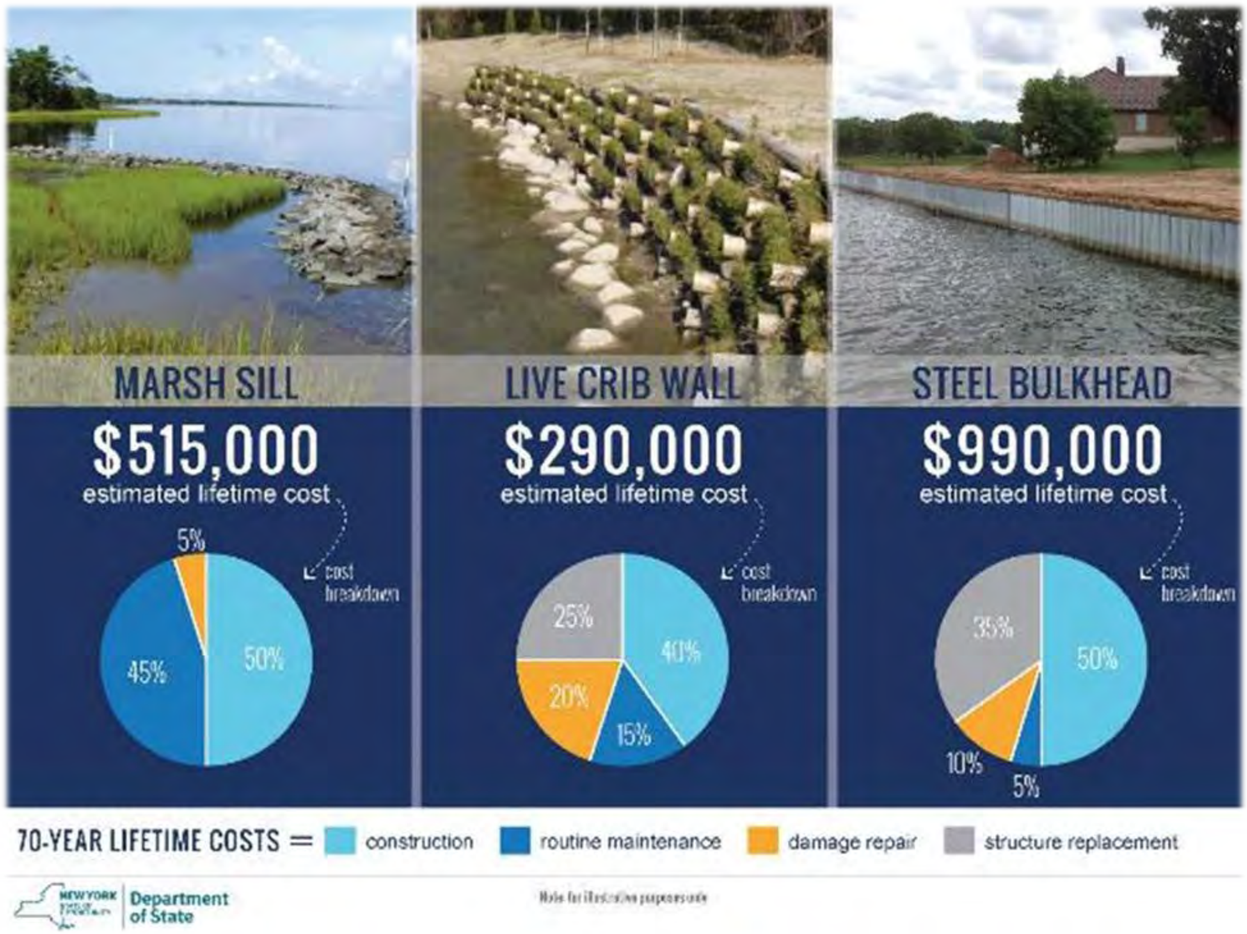
Appendix D: Construction, maintenance and adaptability costs of restored natural and nature-based features compared to hard structural features

Measures to manage flooding and erosion can be evaluated based on the life-cycle costs (i.e., the net present value of planning, design and construction, plus future monitoring, management and replacement) of the measure relative to other management options. An objective benefit-cost analysis can identify options that are most responsible from both a private and public perspective.

Initial construction costs for natural and nature-based features can be considerably less than hard structural features. However, costs are heavily dependent on the environmental setting and the project objectives. Costs for any shoreline feature can vary significantly depending on the existing condition of the local and adjacent environment, need for remediation, availability of materials, hauling distances, prevailing labor rates for the geographic area and other factors (USACE and NOAA, 2015; Rella and Miller, 2014; Allen and Leech, 1997).

In areas where natural and nature-based features are appropriate to manage the level of risk, they can also have lower long-term costs than hard structural features. Maintenance costs for restored and nature-based features may be higher than for hard structural features early in the project life to ensure that vegetation is well-established. However, with proper maintenance, costs can decrease as vegetation takes hold, spreads and strengthens the shoreline, if environmental conditions remain favorable at the site and adjacent areas. If weak spots and/or vegetation are repaired or replanted, the feature will continue to grow and gain strength over time (Allen and Leech, 1997). Nature-based features can also be self-maintaining, with the potential to self-repair after major damaging storm events, and to grow in elevation in response to sea-level rise. The lifespan of these features is not finite, and they can be physically adapted to higher water levels, development and restoration opportunities, if needed (Lamont et al., 2014).

In contrast, hard structural features typically have a high initial construction cost, a finite service life and substantial maintenance, replacement or refurbishment costs after a storm event or at the end of its useful service life (Figure D-1). Hard structural features are typically strong immediately upon completion, but weaken with age. Often, their use also results in hidden costs to the broader community in loss of public environmental co-benefits and because they promote development in high-risk areas under the false assumption that hard structural features provide complete protection.



Credit: NYS DOS.

Figure D-1. This graphic represents cost estimates for 3 shoreline management approaches under a 70-year lifecycle for 500 ft. of shoreline.
The estimates are for installations on the Hudson River under current sea level rise projections. Estimates are from Rella and Miller (2012) and vegetative components for the marsh sill are estimated from USACE (2015). As with any shoreline treatment, costs are site specific and can vary based on many factors, including local labor or material costs, size of the installation or storm incidence. Credit: NYS DOS.

Once constructed, hard structural features are likely to be challenging to adapt to rising sea levels and increasing flood risk. Hard structural features are designed to weather certain conditions based on an acceptable level of risk. They often are designed with a 30-year design life and to withstand the 25- to 100-year flood.[38] However, the frequency of the 100-year flood is projected to increase significantly over the course of this century. Current climate projections for New York City indicate that 100-year floods will recur, on average, approximately once every 65 to 80 years in the 2020s, once every 35 to 55 years in the 2050s, and once every 15 to 35 years in the 2080s (Rosenzweig et al., 2011). Most existing hard structural shoreline features have not been designed to accommodate sea-level rise or changing flood frequency, increasing the likelihood that they will be overtopped in the future (NYS DHSES, 2014). Infrastructure built to withstand the current 100-year flood may be damaged or destroyed if it is not adapted as the risk of flooding increases over time.

Credit: NYS DEC.

Figure D-2. Steel cap of sheet pile bulkhead at Haverstraw Bay Park on the Hudson River that was dislocated by Hurricane Sandy.
Such damage could require significant repair and replacement costs.

[38] See CRRA NYS Flood Risk Management Guidance for discussion of flood probability.

Constructing and retrofitting previously constructed hard structural features to provide the desired level of storm risk reduction as sea levels rise will be challenging and expensive. Hard structural features generally rely on large fixed foundational components. These foundations will either need to be larger now, to accommodate the addition of height to the structure in the future, or be completely rebuilt from scratch when the structure is no longer sufficient to manage risk. Larger hard structures will have more significant impacts on natural resilience measures and the broader co-benefits they provide to the public. In contrast, restored and nature-based features often have smaller components that can be more easily modified to accommodate higher elevations.

Sources

1. Allen, H. H., & Leech, J. R. (1997). Bioengineering for Streambank Erosion Control: Report 1—Guidelines (Technical Report EL-97-8).

2. Lamont, G., Readshaw, J., Robinson, C., & St-Germain, P. (2014). Greening Shorelines to Enhance Resilience: An Evaluation of Approaches for Adaptation to Sea Level Rise. Prepared by SNC-Lavalin Inc. for the Stewardship Center for B.C. and submitted to Climate Change Impacts and Adaptation Division, Natural Resources Canada (AP040). Retrieved from http://www.stewardshipcentrebc.ca/PDF_docs/reports/Greening_Shorelines_to_Enhance_Resilience.pdf

3. New York State Department of Homeland Security and Emergency Services (NYS DHSES). (2014). 2014 New York State Hazard Mitigation Plan.

4. Rella, A., & Miller, J. (2012). Engineered Approaches for Limiting Erosion along Sheltered Shorelines: A Review of Existing Methods. Staatsburg, NY: Hudson River Sustainable Shorelines Project. Retrieved from http://www.hrnerr.org

5. Rella, A., & Miller, J. K. (2014). A Comparative Cost Analysis of Ten Shore Protection Approaches at Three Sites Under Two Sea Level Rise Scenarios. Staatsburg, NY: Hudson River Sustainable Shorelines Project. Retrieved from https://www.hrnerr.org/doc?doc=240577263

6. Rosenzweig, C., W. D. Solecki, R. Blake, M. Bowman, C. Faris, V. Gornitz, R. Horton, K. Jacob, A. LeBlanc, R. Leichenko, M. Linkin, D. Major, M. O'Grady, L. Patrick, E. Sussman, G. Yohe, and R. Zimmerman. (2011). Developing Coastal Adaptation to Climate Change in the New York City Infrastructure-Shed: Process, Approach, Tools, and Strategies. *Climatic Change*, 106: 93–127.

7. U.S. Army Corps of Engineers (USACE) and National Oceanic and Atmospheric Administration (NOAA). (2015). SAGE – Systems Approach to Geomorphic Engineering. Natural and Structural Measures for Shoreline Stabilization Brochure.

8. U.S. Army Corps of Engineers (USACE). (2015). NACCS: North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk. Retrieved from *http://www.nad.usace.army.mil/CompStudy*

Appendix E: Hard structural measures along our coasts, streams and lakes

Hard structural erosion and flood risk management measures support a variety of human needs and activities. They provide weight-bearing foundations; protection from the elements; privacy and security; conduits for transportation; systems of water, food supply and waste removal; heating, cooling and electricity; and many other products and services.

However, hard structural measures alter natural water flow and sediment transport processes. They can change the ability of the shore zone to respond naturally to changing conditions, which can result in loss of habitat and species diversity (Meadows et al., 2005; Miller et al., 2015). Hard structural measures can also cover portions of the land/water interface, impeding plant growth and animal movement. Streambank armoring, culverts and dams can disrupt sediment transport processes inland, causing erosion problems on adjacent properties, affecting water quality and changing sediment transport to coastal areas. Thousands of dams have been built throughout New York, impacting water and sediment movement, sometimes causing localized upstream flooding and increasing the risk of catastrophic loss downstream when dams fail.

Erosion protection structures impact neighboring shoreline properties in several ways. During the engineering and planning of a hard erosion protection structure, it is important to consider all of these factors to minimize the risk to properties both adjacent to, and downdrift of, the project site. Unavoidable impacts from erosion protection structures can sometimes be mitigated. Examples of potential impacts are below.

Negative effects of hard structural measures on shoreline reaches

- Reduction of available sediment: Hard structural erosion management measures are intended to eliminate sediment loss at a specific location (revetments, seawalls, for example), or trap sediment out of the littoral system (groins and jetties). While this may be effective at the specific site, it may have impacts on adjacent shoreline areas. For example, erosive bluff areas act as a sediment source to feed beaches downdrift. When a hard structural feature is installed, the amount of available sediment available in the system is reduced, which could have a negative impact on the shoreline downdrift. Sediment starvation can be partially mitigated through the addition of sediment back into the system through beach nourishment on the downdrift side of the hard structural feature, such as a groin.
- Sediment transport interruption: Shore perpendicular structures such as groins and jetties are designed to interrupt sediment transport in order to build up sediment on the up drift side of the structure. If not properly designed, this can lead to a dramatic reduction of sediment on the downdrift side of the structure, leading to erosion on the downdrift side. One design method to reduce this impact is to taper groins both

vertically and horizontally, allowing for more natural sediment movement along the shorelines (Figure E-1).

- Wave reflection: Waves rarely break perpendicular to the shoreline, and most often come in at an angle. When this happens, hard structures reflect wave energy at an angle. This can lead to increased erosion at the immediate ends of an erosion protection structure. Designs should aim to minimize this effect.
- Scour: Vertical erosion protection structures such as seawalls reflect more energy than a natural shoreline or a sloped erosion protection structure (such as a revetment). This reflected energy can scour out the seafloor immediately seaward of the erosion protection structure. This can both erode any fronting beach and deepen the area in front of the structure eventually leading to undermining and failure of the structure. Designs should aim to minimize this effect by using sloped shore parallel structures wherever possible, and incorporating toe stone for scour protection when a vertical structure is proposed.

Credit: NYS DEC.

Figure E-1. This groin is interrupting sand transport along the shoreline (moving left to right) to capture sand and stabilize the updrift beach.
However, it is also reducing the amount of sediment available to feed and maintain downdrift beaches and dunes.

Systemic effects of hard structural features

- Public access: Hard structural shoreline features, especially vertical structures, can negatively affect public access to the shore areas over the long term. As sea levels rise, they create barriers that will reduce or eliminate shoreline access and navigation currently accessible to the public.
- Cumulative effects: In many cases, the installation of structural measures in one location creates new problems in nearby areas, necessitating additional management actions or new structures.[39] Thus, the use of one hard structural measure often leads to the construction of more. Once several hard structural measures are in place they can have cumulative impacts on the system. Cumulative impacts are the combined effects of multiple actions, including their indirect, secondary, long term and synergistic effects.[40] Multiple shoreline armoring structures within a natural system act together to magnify the effects on the natural system and sediment supply. Natural features that could reduce risk can be impaired as a result of cumulative effects from multiple structures, or from a combination of development encroachments, fill, excavation, weather and other natural processes, amplified by climate change.
- Inducement of at-risk development: Structural flood and erosion defenses do not eliminate risk (NRC, 2013). Investigating levee and floodwall failures in New Orleans during Hurricane Katrina, the National Academies found "…the risks of inundation and flooding never can be fully eliminated by protective structures no matter how large or sturdy those structures may be" (NAE and NRC, 2009; Fox-Rogers et al., 2016; Di Baldassarre et al., 2013; Barendrecht et al., 2017). However, the perception that large-scale flood protection structures eliminate risk often encourages additional development in high hazard and exposure locations (White, 1945). This can indirectly increase vulnerability and lead to the need for additional and costlier flood protection (Kates et al., 2006). In this case, if the structural protection fails or is overcome, damages may be far higher than expected had development been managed to reduce exposure and vulnerability to floods. Development protected by any measures should always include redundant measures to avoid damage in the event the structures don't fully function or are overcome.

Where hard structures are appropriate

Hard structural measures to manage flooding and erosion exist throughout New York State. Some hard structural measures, such as levees, seawalls and channelized streams are designed

[39] See for example: U.S. Army Corps of Engineers, Sea Gate Project, Coney Island, New York, at *http://www.nan.usace.army.mil/Missions/CivilWorks/ProjectsinNewYork/RockawayInlettoNortonPoint(ConeyIsland)/SeaGateMoreInfo.aspx*

[40] Synergistic effects occur where two or more actions combine to cause greater environmental impacts than either two actions individually.

to reduce flooding. Bulkheads, revetments, groins/jetties and breakwaters are typically designed to reduce both flooding and coastal erosion (USACE, 2013).

Hard structural measures can be necessary to provide for water-dependent uses or where development or critical infrastructure cannot otherwise be secured from erosion and flooding. Bulkheads and piers may be necessary for working waterfronts where vessels need deep water and docking. Bridge abutments and bridge scour protections are necessary elements for transportation infrastructure that is located over water. Jetties and breakwaters may provide for navigation and recreation (i.e., fishing) and protect working waterfronts.

Hard structural stormwater management is appropriate when there is not enough space for natural or nature-based solutions to filter or store the same amount of water; where the below grade substrate cannot adequately absorb stormwater (e.g., clay soils and bedrock); and for temporary use during construction projects. For example, above-ground or underground cisterns can capture water, from a rooftop or parking lot, to be released into the stormwater system slowly after a rainfall event. Such detention basins can be very effective at reducing stormwater flooding in highly urbanized areas.

There are situations where it may be determined that only a hard structural measure is appropriate. Locations where hard structures may be reasonable and necessary include the following:

- where other alternatives will not provide the necessary level of protection;
- where water dependent uses such as maritime commerce which require both calm waters and vertical structures for vessels;
- where highway and roadway infrastructure cross a waterbody (e.g., bridges or culverts);
- where critical infrastructure (water and wastewater facilities, electrical generating facilities, petroleum storage and distribution) and existing urban development cannot be relocated without major disruption to communities;
- where existing critical infrastructure or facilities are at high risk and alternatives are unavailable;[41]
- as a temporary measure to enable more sustainable adaptive measures to be employed; or
- where there is not enough space to allow for other alternatives.

Designs must balance adequate protection for the land use with the public co-benefits of natural and nature-based features. Many nature-based approaches are better suited for shoreline defense in low- to medium- energy wave environments. However, nature-based features are more complex to design and build in medium- and high- energy wave

[41] For definitions of critical infrastructure and facilities see CRRA Flood Risk Management Guidance.

environments, where more structure may be necessary. Critical assets in higher energy environments are also more likely to require hard structural features (PDE and Rutgers, 2012).

Features that have more hard structural components can still be ecologically enhanced, to provide co-benefits, like habitat and water filtration, in areas where nature-based features alone won't sufficiently reduce risk. Bulkheads, revetments or seawalls can incorporate vegetation or other living material and vary the form or composition of the structure itself. Examples include incorporating terraced or roughened edges, using habitat-friendly materials (e.g., timber, logs or hollow concrete modules) or introducing folds along the length of a structure for habitat. These enhancements alone do not make a feature nature-based, but they may provide some aesthetic, ecological and/or environmental value to the structure, while providing the same high-level of protection afforded by the base structure. These enhanced structures have been used increasingly in urban settings where a high level of protection is required and where space is limited (Figure E-2) (Rella and Miller, 2012; DeWeerdt, 2012).

Credit: NYC Parks.

Figure E-2. Harlem River Park 'Design the Edge' project.
This project is a primarily a hard structural measure, however, it includes gabion baskets and a porous "green" wall intended to improve its ecological value over a flat wall, by creating structural diversity. The project also includes several levels of redundant flood risk mitigation measures and expands recreational opportunities compared to the former bulk-headed shoreline.

Sources

1. Barendrecht, M., Viglione, A., & Bloschl, G. (2017). A Dynamic Framework for Flood Risk. Water Security, 1: 3–11. Retrieved from *https://www.sciencedirect.com/science/article/pii/S2468312416300232*

2. DeWeerdt, S. (2012). How to Build a Living Seawall. Conservation. University of Washington. Retrieved from *http://conservationmagazine.org/2012/03/how-to-build-a-living-seawall/*

3. Di Baldassarre, G., Kooy, M., Kemerink, J., & Brandimarte, L. (2013). Towards Understanding the Dynamic Behavior of Floodplains as Human-Water Systems. Hydrology and Earth System Sciences, 17: 3235–3244.

4. Fox-Rogers, L., Devitt, C., O'Neill, E., Brereton, F., & J. Clinch. (2016). Is There Really "Nothing You Can Do"? Pathways to Enhanced Flood-Risk Preparedness. Journal of Hydrology, 543: 330–343.

5. Kates, R., Colten, C., Laska, S., Leatherman, S. (2006). Reconstruction of New Orleans after Hurricane Katrina: A Research Perspective. Proceedings of the National Academy of Sciences of the United States of America. Retrieved from *https://doi.org/10.1073/pnas.0605726103*

6. Meadows, G. A., Mackey, S. D, Goforth, R. R, Mickelson, D. M., Edil, T. B., Fuller, J., Guy, D. E., Meadows, L. A., Brown, E., Carman, S. M., Liebenthal, D. L. (2005). Cumulative Habitat Impacts of Nearshore Engineering. *J. Great Lakes Res.*, 31 (Supplement 1): 90–112.

7. Miller, J. K., Rella, A., Williams, A., & Sproule, E. (2015). Living Shorelines Engineering Guidelines. Stevens Institute of Technology. Prepared for the New Jersey Dept. of Environmental Protection

8. National Academy of Engineering (NAE) and National Research Council (NRC). (2009). The New Orleans Hurricane Protection System: Assessing Pre-Katrina Vulnerability and Improving Mitigation and Preparedness. Washington, D.C.: The National Academies Press. Retrieved from *https://doi.org/10.17226/12647*

9. National Research Council (NRC). (2013). Levees and the National Flood Insurance Program: Improving Policies and Practices (p. 97). Washington, DC: The National Academies Press. Retrieved from *https://doi.org/10.17226/18309*

10. Partnership for the Delaware Estuary (PDE) and Rutgers' University Haskin Shellfish Research Laboratory. (2012). Final Report: New Jersey Living Shoreline Possibilities. Submitted to the Dodge Foundation (PDE Report No. 12-05).

11. Rella, A., & Miller, J. (2012). Engineered Approaches for Limiting Erosion along Sheltered Shorelines: A Review of Existing Methods. Staatsburg, NY: Hudson River Sustainable Shorelines Project. Retrieved from *http://www.hrnerr.org*

12. U.S. Army Corps of Engineers (USACE). (2013). Coastal Risk Reduction and Resilience. Washington, D.C.: U.S. Army Corps of Engineers Civil Works Directorate.

13. White, G.F. (1945). Human Adjustment to Floods: A Geographical Approach to the Flood Problem in the United States. University of Chicago Press.

Appendix F: Considerations for the use of natural resilience measures in the context of a changing environment

Natural forces create natural features. These forces can also change, move or damage them. Where development does not hinder their movement, natural features can move or otherwise adapt and continue to provide risk reduction and other valuable services. However, climate change and land use practices may accelerate or intensify the effects of natural forces, making it more difficult for existing features and systems to maintain equilibrium or respond and recover. This section will provide information on potential impacts to natural resilience measures from climate change and considerations for managing these impacts.

Examples of natural and climate change impacts to natural resources and processes are below. There is still uncertainty about the magnitude and rate at which these changes will occur. Climate change may also have cascading effects on other sectors such as the economy and transportation systems, but this section focuses on the impacts to the risk-reduction capacity of natural features.

Examples of the effects of climate change on natural features[42]

- Sea-level rise
  - Sea-level rise is accelerating along the ocean coast. Tidal wetlands and other features that are not able to maintain elevation (through sediment build-up) or migrate inland, due to encroaching development, manmade barriers or steep topography, will "drown", transitioning to mudflats, shoals or open water (Warren-Pinnacle Consulting, 2014; Tabak et al., 2016).[43] These trends are already being observed in Long Island.
  - Other ocean coastal features like beaches, dunes and barrier islands can maintain their elevation or migrate landward in response to sea-level rise, as long as adequate sediment is available, through sediment transfer from the seaward side to the bayside (termed 'island rollover'). However, if coastal development continues to impede these natural processes these features will become increasingly narrow over time, increasing the likelihood of breaching and overtopping.
- Hurricanes and severe storms
  - Wind and water from severe storms can drastically change dunes, beaches and barrier islands, altering or diminishing their ability to protect nearby human assets.

[42] See also NYS DEC (2015).
[43] Information on tidal wetland trends can be found at *http://www.dec.ny.gov/lands/5113.html*

- Flooding can cause the erosion of streambanks and channels and carry large quantities of sediment downstream. Historic channels and floodplains may move or grow to accommodate changes (Rosenzweig et al., 2011).
- Forests can be damaged or lost by wind and ice damage or saturation of soils.
- Increased precipitation due to climate change may lead to more acidic river runoff (Rosenzweig et al., 2011).

- Ocean acidification
    - Increased carbon dioxide in the atmosphere is being absorbed into the oceans causing ocean water to become more acidic. Consequently, organisms that have calcium carbonate shells and structures have difficulty building and maintain their structures (Fabry et al., 2008; NOAA, n.d.).
    - Higher temperatures, extreme heat and drought
        - Large lakes are no longer freezing over. Ice that is anchored to a lakeshore or streambank can form a protective barrier from erosion. Reduced ice cover in lakes and rivers means that chunks of detached ice can move onshore or alongshore and cause erosion.
        - Increases in temperature are allowing the expansion of some invasive species into New York, like Kudzu.
        - Extreme heat and drought stresses plants and animals. Vegetation can be stunted or die, reducing its ability to absorb and slow water and stabilize soils through root systems.
        - Increased average temperatures will cause the range of southern species to expand northward. This may have wide-ranging and unpredictable ecosystem impacts.

Sources

1. Fabry, V. J., Seibel, B. A., Feely, R. A., & Orr, J. C. (2008). Impacts of Ocean Acidification on Marine Fauna and Ecosystem Processes. ICES Journal of Marine Science: Journal du Conseil, 65(3), 414–432.

2. National Oceanic and Atmospheric Administration (NOAA). (n.d.). What is Ocean Acidification? Retrieved from *http://oceanservice.noaa.gov/facts/acidification.html*

3. New York State Department of Environmental Conservation (NYS DEC). (2015). Observed and Projected Climate Change in New York State: An Overview Developed for the Community Risk and Resiliency Act (CRRA) Drafting Teams 12/31/2015. Retrieved from *http://www.dec.ny.gov/docs/administration_pdf/climbkgncrra.pdf*

4. Rosenzweig, C., Solecki, W., DeGaetano, A., O'Grady, M., Hassol, S., & Grabhorn, P., Eds. (2011). Responding to Climate Change in New York State: The ClimAID Integrated

Assessment for Effective Climate Change Adaptation (Chapter 4, Section 4.2). Albany, NY: New York State Energy Research and Development Authority (NYSERDA).

5. Tabak, N., Laba, M., & Spector, S. (2016). Simulating the Effects of Sea Level Rise on the Resilience and Migration of Tidal Wetlands along the Hudson River. PLoS ONE, 11(4): e0152437.

6. Warren-Pinnacle Consulting. (2014). Application of Sea-Level Affecting Marshes Model (SLAMM) to Long Island, NY and New York City: Final Report. Prepared for the New York State Energy Research and Development Authority. Retrieved from *https://www.nyserda.ny.gov/-/media/Files/Publications/Research/Environmental/SLAMM%20report.pdf*