Coastal Adaptation Toolkit

Adapting to Climate Change in Coastal Communities of Atlantic Canada

Part 3 Coastal Intervention Options & Engineering Considerations

January 2023

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Authors

Vincent Leys, CBCL; Sarah van den Heuvel, CBCL; Aline Kaji, CBCL

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Disclaimer

The toolkit is intended for informational purposes only. The information provided is not a substitute for site-specific professional advice, nor does the information contained in the tools replace consultation with engineering, land use planning, and/or earth science professionals. The information provided does not preclude the need to engage with relevant jurisdictions in regulatory and permitting processes. The authors make no representation as to its accuracy and the claims made by the articles from which it was derived.

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PART 3 Coastal Intervention Options and Engineering Considerations

Foreword

The Atlantic Provinces of Canada have established enduring patterns of land use and development at the coast. All of the region's coastal communities are vulnerable to marine coastal hazards and climate change impacts; their future relies on adapting to the impacts of climate change.

Adapting to Climate Change in Coastal Communities of the Atlantic Provinces, Canada: Land Use Planning and Engineering and Natural Approaches provides guidance on strategies and tools to manage climate change-driven sea level rise and coastal flooding and erosion. This set of three guidance documents supports the CLIMAtlantic web-based Coastal Adaptation Tool (https://climatlantic.ca/coastal-adaptation/). Combined, these resources help decision-makers/property owners define their needs to reduce risk, and select the most appropriate options for their community's coastal context and climate change impact challenges.

Part 1 Guidance for Selecting Adaptation Options*,* introduces climate change adaptation for the coastal regions of the Atlantic Provinces. It describes the five main adaptation approaches, describes climate change impacts in the Atlantic Region, characterizes the coastal environments, presents criteria for adaptation decision-making, and links adaptation tools and strategies to the coastal settings of the Atlantic Provinces.

Part 2 Land Use Planning Tools Adaptation Options, presents over 50 land use planning tools for coastal climate change adaptation. The tools and examples in this guidance document are the land use planning options of the CLIMAtlantic web-based Coastal Adaptation Tool. The document also includes overviews of the land planning and management frameworks and legislation that could support coastal climate change adaptation in each of the four Atlantic Provinces and First Nations.

Part 3 Coastal Intervention Options and Engineering Considerations*,* presents over two dozen intervention options to manage coastal flooding and erosion, describes the suitability of the tools for different coastal conditions and climate change adaptation objectives (e.g., short to long-term, low, medium or high cost), and identifies the technical and permitting requirements for the adaptation approaches. The tools and examples in this volume are the engineering options of the CLIMAtlantic web-based Coastal Adaptation Tool.

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Preface

The *Coastal Adaptation Toolkit, Adapting to Climate Change in Coastal Communities of Atlantic Canada, Part 3, Coastal Intervention Options and Engineering Considerations* presents over two dozen intervention options available for managing the climate change impacts of coastal flooding and erosion. The information in this set of guidance documents will help decision-makers select land use planning tools and intervention measures that are appropriate for the community. Technical terminology used throughout this report is defined in Chapter 5: Glossary. The tools described in this guidance document are also the land use planning outputs for CLIMAtlantic's web-based Coastal Adaptation Tool.

Additional resources can be found in Chapter 6: Further Reading.

Part 3 Coastal Intervention Options and Engineering Considerations begins with a summary of adaptation and of the relationship between climate change, coastal processes, and coastal risk. It is the goal of adaptation to reduce risk and vulnerability to climate change impacts. Part 1 Guidance for Selecting Adaptation Options describes adaptation, coastal processes, and coastal systems in detail.

> This summary guidebook is intended as an informative checklist to evaluate potential solutions within the context of the web-based Coastal Community Adaptation Tool. It is not a design guideline, and it is not a substitute for site-specific professional engineering and planning advice.

The focus of Part 3 is to provide an inventory of coastal interventions, with illustrated examples of their application to manage coastal flooding or erosion, and summary information ─ organized in tables ─ to compare the different tools based on:

- Where the tool is needed (type of coast and its exposure to waves).
- What the tool does.
- What the regulatory requirements are (which government department controls what you can or cannot do in the area where the tool would be used).
- What the high-level estimated cost of the tool will be depending on the availability of materials and approximately how long the tool will last.

Chapter 1: Adaptation Approaches to Coastal Risk

Coastal processes become coastal hazards when people occupy the coastal zone without regard for the space that is needed to accommodate wind, waves and tides, and without regard for how landform, geology, and habitats respond to these forces. Coastal hazards and impacts to people and the environment result from erosion, structural failure, and flooding. These processes are accelerating and becoming more intense, and therefore more hazardous in some areas because of climate change. In the Atlantic Provinces, these changes include sea level rise, increased precipitation, stronger storms, and diminished sea ice.

Strategies for coastal adaptation involve reducing, or even eliminating, the coastal hazard, or reducing the impact. The four main strategies for adaptation are **Avoid**, **Retreat**, **Accommodate**, **Protect**. Prior to selecting an approach, it is important to develop Risk Understanding for stakeholders (also referred to **Procedural** throughout the resources). More information about these strategies is found in *Part 1: Guidance for Selecting Adaptation Options.*

It is important to acknowledge that the adaption strategies discussed cannot be implemented without consideration of the entire system in which the site exists. Natural system processes need to be considered and incorporated for coastal intervention measures to be resilient to disturbances, and sustainable. Characterizing baseline system conditions and potential future changes in the natural system of the site in consideration is crucial for the design of coastal interventions. "Systems-based" approaches account for such interactions (physical, biological, social), temporal scales, and spatial scales to develop informed, effective designs. For further reading on whole system approaches, refer to the Canadian Standards Association*'s, Nature-Based Solutions for Coastal and Riverine Flood and Erosion Risk Management.*[1]

Procedural (also referred to risk-understanding) activities include projects and activities that aim to educate people about climate change and how it can affect the coast and coastal communities; collect climate information and local data about the coast to guide local adaptation decisions; organize the information so that it is available and easy to understand, such as in maps; and use the information to make climate change resilient communities through community and land use policy and planning. Activities and initiatives in this category may stand alone (e.g., an education program) but they usually support the other strategies or provide an overarching framework for adaptation planning.

Avoid is a strategy for discouraging or preventing development in hazardous places or places that might become hazardous in the future. The strategy requires identifying such areas and the risks to future development. Avoiding hazardous places and keeping development away from them may have added benefits such as environmental protection and increased public access to the coast.

Retreat, or managed retreat is a strategy to relocate people and infrastructure away from hazardous coastal areas to areas with lower risks. The strategy is a long-term adaptation approach in high-risk areas. This strategy increases public safety and can be used instead of replacing expensive protection measures over time. There are two types of retreat, managed retreat and abandon. When retreat is used in this document it is almost always referring to

[1] Vouk, I., Pilechi, V., Provan, M., Murphy, E. (2021). Nature-Based Solutions for Coastal and Riverine Flood and Erosion Risk Management. Canadian Standards Association, Toronto, ON. Accessed at: https://www.csagroup.org/article/research/nature-based-solutions-for-coastal-and-riverine-flood-and-erosion-risk-management/

managed retreat. With managed retreat, decisions are made about what to relocate and what areas to leave to revert to natural systems. The second type of retreat is abandonment. Abandonment does not involve pre-planned relocation. Abandonment may be necessary in emergency situations if no other options exist.

Accommodate, allows for continual use of coastal lands but changes the use of the land or the current infrastructure. Changes in land use could include changing how shorelines are accessed. Changes to infrastructure may include designing to accommodate flooding with raised, flood proofed or floating structures.

Protect is often a reaction to coastal erosion or flooding. Protection is the most common form of adaptation in coastal areas throughout the world. It almost always involves some intervention at the coast. Protection aims to allow the current uses of the land to continue without change. Protection methods are usually short-term solutions to coastal issues and must be upgraded over time. Protection is typically expensive over the long-term and may become more expensive with climate change as sea level rises over the next century. Protection options can be based on **hard structures** where space is limited typically along a developed coast, or **soft approaches** (i.e., nature-based) where enough space is available seaward of the infrastructure being protected. Soft measures should always be considered to integrate ecological and engineering design perspectives.

These strategies are not mutually exclusive; adaptation often involves a combination of approaches. Furthermore, given the uncertainty in climate change predictions, stakeholders and decision makers should create a strategic vision of the future, committing to short-term actions, while establishing a framework to guide future actions. Example of such adaptive planning approaches are found in, *Dynamic Adaptive Policy Pathways.*[2]

[2] Haasnoot, M., Kwakkel, J. H., Walker, W. E., & Ter Maat, J. (2013). Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. Global environmental change, 23(2), 485-498.

Chapter 2: Engineering Considerations

This chapter describes various aspects that need to be considered when evaluating potential coastal interventions that can be applied to mitigate climate change risks. Basic engineering considerations include coastal processes, climate change impacts, engineering project planning, construction methods, impacts of project on coastal processes and the environment, regulatory framework, costs and opportunities for co-benefits. These aspects are discussed for each of the conceptual interventions described in Chapter 3 and summarized in tables in the Appendix.

2.1 Coastal characteristics, physical processes and climate change impacts

Engineering strategies for climate change adaptation at the coast are designed with attention to the dynamic nature of the coastal environment and anticipation of projected changes in coastal conditions into the future. Part 1 Guidance for Selecting Adaptation Options provides an overview of coastal processes and climate change impacts in the Atlantic Provinces. Understanding the coastal characteristics and local physical processes is the first step to define which interventions are suitable at each location.

In summary, the goal of engineering strategies is to manage or reduce coastal hazard risk– flooding and erosion — by preventing or lessening the impact of water level and waves from interfering with infrastructure and land uses along the coast. Engineering design accounts for coastal form and geology; the current and projected water levels in the coastal shore zone – high tide, storm surges, seiching (temporary disturbance of water levels), sea level rise and wave run-up; the shore currents and the forces of the waves and tides and anticipated changes in these forces with climate change; and the coastal sediment transportation system of erosion, transport and deposition.

Climate change impacts that will affect the coastal regions of the Atlantic Provinces are sea level rise, potentially stronger storms, increased precipitation and loss of sea ice cover. The effects of these impacts are higher water levels that will increase the reach and frequency of flooding and stronger wave impacts that will increase coastal sediment transport and the rate of erosion. Flooding and erosion are threats to public safety and infrastructure (Figure 3.1).

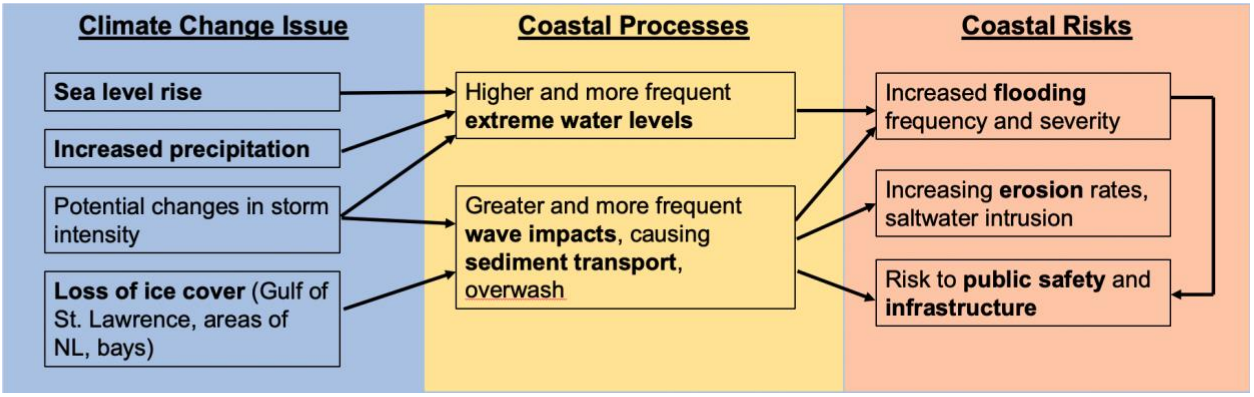

Figure 3.1 Climate change impacts on coastal hazards (Vincent Leys, CBCL Limited).

2.2 Co-benefits of nature-based solutions

Engineering interventions for coastal protection often involve conventional approaches, such as concrete structures (seawalls, for example). Such conventional approaches are termed grey infrastructure or hard coastal protection measures. Another approach to coastal protection is nature based, or green infrastructure. Green infrastructure mimics or depends on the natural environment and systems to provide protection. Nature-based solutions can aid in flood and erosion risk management while contributing to ecosystem restoration and biodiversity enhancement. Green-grey coastal protection infrastructure exists on a continuum as combinations of the approaches can be used as hybrid techniques.

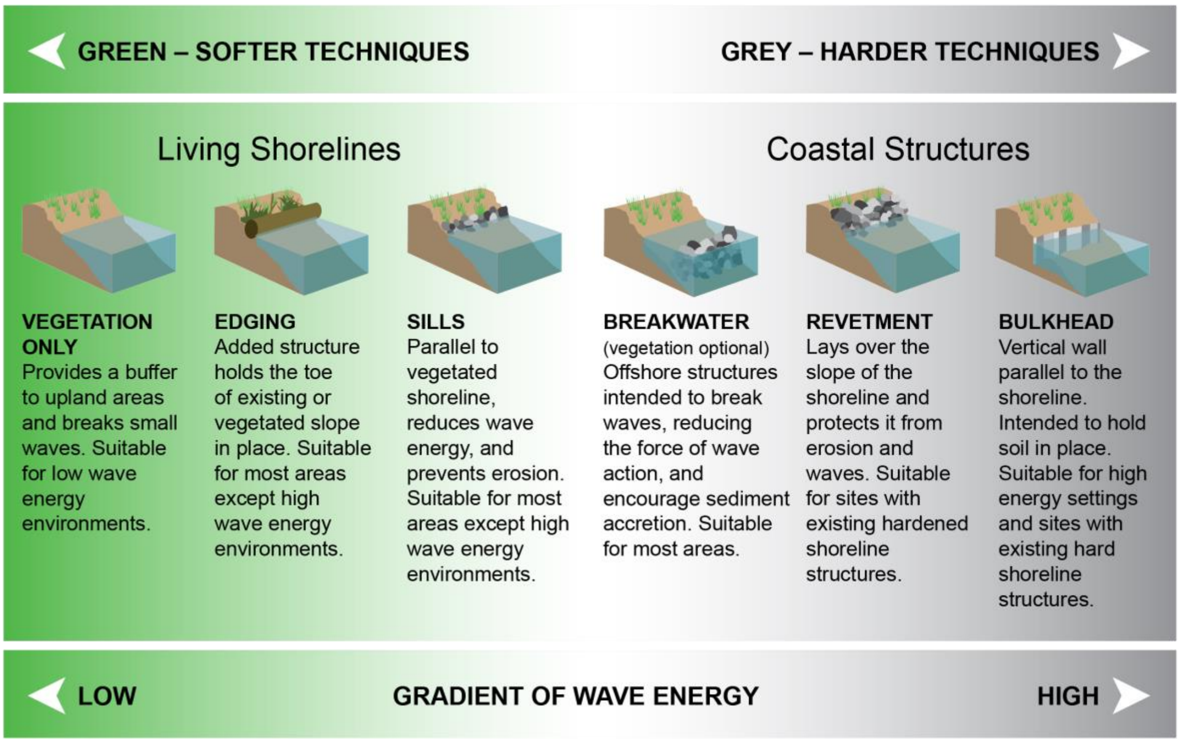

Figure 3.2 Continuum of green (soft) to gray (hard) shoreline protection techniques (modified from Guidance for Considering the use of Living Shorelines, NOAA)

Combining nature-based solutions with grey infrastructure can provide higher levels of protection from coastal hazards when implemented using a systems-approach as described in Chapter 1: Adaptation Approaches to Coastal Risk. For further reading on nature-based solutions for coastal protection, refer to the U.S Army Corps of Engineers' *International Guidelines for Natural and Nature Based Features for Flood Risk Management*[3] and/or the Canadian Standards Association's *Nature-Based Solutions for Coastal and Riverine Flood and Erosion Risk Management.*[4]

3 Bridges, T. S., J. K. King, J. D. Simm, M. W. Beck, G. Collins, Q. Lodder, and R. K. Mohan, eds. 2021. International Guidelines on Natural and Nature-Based Features for Flood Risk Management. Vicksburg, MS: U.S. Army Engineer Research and Development Center. Accessed at: https://ewn.erdc.dren.mil/?page_id=4351
4 Vouk, I., Pilechi, V., Provan, M., Murphy, E. (2021). Nature-Based Solutions for Coastal and Riverine Flood and Erosion Risk Management. Canadian Standards Association, Toronto, ON. Accessed at: https://www.csagroup.org/article/research/nature-based-solutions-for-coastal-and-riverine-flood-and-erosion-risk-management/

2.3 General knowledge needs and engineering considerations

Coastal infrastructure projects must consider many factors from the project planning stage to construction; examples are listed below.

The combination of all local factors makes each project unique and requires 'big-picture' thinking.

Project planning and objectives include, but are not limited to:

- function, including flood or erosion mitigation,
- lifetime,
- cost-benefit and maintenance considerations – including sources of funding for construction and for maintenance,
- socio-economic considerations, and
- aesthetics.

Construction considerations include, but are not limited to:

- availability and suitability of materials,
- stability and erosion (scour) issues during construction,
- sequencing of construction, and
- scheduling related to weather and permits depending on the season.

Impacts of project on coastal processes include, but are not limited to:

- regional sediment budget (potential blockage of sediment movement), and
- potential changes to currents, tidal flows and/or water quality.

Impacts of coastal processes on project include, but are not limited to:

- elevation relative to extreme water levels,
- structural stability under storm and ice impacts,
- seafloor / ground stability,
- sediment transport and erosion rates, and
- designing for changing conditions under sea level rise.

The sections that follow provide further information on the long-term climate change implications for coastal infrastructure planning and design.

2.4 Regulatory considerations

The degree of regulatory approval requirements associated with the engineered climate change adaptation options presented in this report vary depending on many factors. These factors include the presence of environmentally sensitive areas, level of public interest, source of funding, land ownership and how the adaptation options will impact the area. Included here is a qualitative evaluation of the level of regulatory approval requirements based on the nature of the disturbance for each adaptation option (i.e., which government departments will have to approve the project based on how much the intervention will impact the natural environment).

Consider regulatory requirements and timelines, particularly for interventions in environmentally sensitive areas with public concern. Part 2 ***Land Use Planning Tools Adaptation Options*** contains a thorough compilation of regulations and policies.

Regulation Boundaries – Regulatory jurisdiction for coastal projects is complex and differs for each province. A jurisdiction is the area or activity that a government body or other organization has control over. The boundaries of coastal regulatory jurisdiction can be generally divided into two regions, the terrestrial (land) and maritime (seawater) zones. In accordance with the Ocean Act, a federal statute, the federal government has jurisdiction over marine waters within the Maritime zone from the ordinary low water mark to the outer boundary of the exclusive economic zone, 200 nautical miles (370 km) seaward.[5] The Ocean Act further divides the maritime zone into the following regions:[6]

- internal waters (all waters landward of a coastal state's jurisdictional coastline),
- territorial sea (0–12 nautical miles),
- contiguous zone (12–24 nautical miles),
- exclusive economic zone (12–200 nautical miles),
- continental shelf (12–200 nautical miles, but can be farther under certain circumstances), and
- high seas (the area beyond the outer limit of a coastal state's continental shelf).

Some provincial statutes also contain legislation regulating activities in the marine zone. Provincial legislation often contradicts the Ocean Act assertion of federal jurisdiction and claims jurisdiction within the territorial sea and beyond, such as the Bay of Fundy. The spatial boundaries of provincial jurisdiction related to the management of natural resources, aquaculture, Crown land and environmental protection vary and are explicitly detailed in the corresponding legislation and regulations.

The majority of terrestrial environmental regulatory jurisdiction is held by the provincial governments or has been granted by the provinces to municipal governments. See Part 2 for an overview of terrestrial environmental and planning regulatory jurisdiction in the Atlantic provinces. Exceptions include projects or undertakings being conducted on federal Crown land or that involve trans-boundary resources or activities; fisheries and navigation for example. The federal government may also have environmental regulatory jurisdiction if the project involves federal funding.

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[5] East Coast Environmental Law. (2010). East Coast Environmental Law Summary Series, Summary Series Volume VIII. Fall 2010. Retrieved from http://www.ecelaw.ca/53-summary-series-v8/file.html

[6] DFO. (2014). Canada's Ocean Estate. A Description of Canada's Maritime Zones. Retrieved from http://www.dfo-mpo.gc.ca/oceans/canadasoceans-oceansducanada/marinezones-zonesmarines-eng.htm

In accordance with Section 35 of the *Constitution Act*, the rights of aboriginal peoples are protected by legislation. Aboriginal rights refer to practices, traditions and customs that distinguish the unique culture of each First Nation and were practiced prior to European contact.[7] The Crown has a legal duty to consult aboriginal groups if Crown conduct has the potential to adversely impact Aboriginal rights, including title and treaty rights. The Crown duty to consult is undertaken for many regulatory project approvals, licensing and authorization of permits. Aboriginal consultation may affect approval timelines and results.

Regulatory Authorities – The Department of Fisheries and Oceans (DFO) and Transport Canada (TC) are the most common federal permitting authorities involved in coastal projects and undertakings. DFO is responsible for the management of Canadian fisheries for both marine and inland waters, including the protection of commercial, recreational, and aboriginal fisheries pursuant to Section 35 of the *Fisheries Act*. Authorization pursuant to Section 35(2) of the *Fisheries Act* may be required for projects that adversely impact fish habitat. Applications for *Fisheries Act* authorization must include fisheries impact offsetting projects (i.e., additional projects that replace fish habitat which may be lost when a protection project is built).

Transport Canada has jurisdiction over navigational hazards as per the *Navigation Protection Act* (NPA). NPA approvals in Atlantic Canada are required for works within the Atlantic Ocean, Bras d'Or Lake, Saint John River and the LaHave River. The inner boundary of the Atlantic Ocean is defined as the extent of the higher high water mean tide (the average from all the highest levels reached by the water surface during 19 years of predictions).

Provincial regulatory permitting authorities have jurisdiction over environmental protection, land use, provincial parks and management areas, provincial Crown land, beaches and aquaculture. The organizational structure of the regulatory authorities and the regulatory statutes vary among provinces. Table A.4 in the Appendix shows generalized jurisdictional responsibility and the corresponding regulatory authorities for each Atlantic Canadian province. *Part 2, Land Use Planning Tools and Adaptation Options*, covers provincial regulations and policies in detail.

Evaluation – The potential degree of regulatory permitting requirements has been qualitatively divided into low, medium and high. The preliminary evaluation of the degree of regulatory permitting requirements associated with the intervention options is based exclusively on the impact each intervention has on the surrounding natural environment.

- **Low –** potential for notification requirements;
- **Medium –** potential for authorization or permit which may include regulatory application submission and review by regulatory authority; and
- **High –** potential for multi-jurisdictional approval requirements which may include an Environmental Impact Assessment/ Environmental Assessment.

This information is included in the outcomes of the CLIMAtlantic web-based decision-support tool, *Coastal Adaptation Tool*.

[7] 6 AANDC. (2014). Aboriginal Rights. Retrieved from https://www.aadnc-aandc.gc.ca/eng/1100100028605/1100100028606

2.5 Basic cost considerations

Costs and materials used in each intervention measure can vary greatly depending on site conditions and material availability. For example, along the Bay of Fundy and the Atlantic seaboard, armour stone is generally available in the local quarries. In contrast, along the Northumberland Strait and Prince Edward Island the local rock is softer and generally not suitable for shoreline armouring. Good quality armour stone has to be carried over longer distances, greatly increasing construction prices.

When it comes to costs, consider every new project a prototype tailored to site-specific conditions.

Indications on the typical cost ranges and potential maintenance requirements for the coastal intervention options were developed based on feedback from engineers at various levels of government, local experience, and literature sources. The results are summarized in Table A.6. This table should be used with caution as a preliminary screening tool only.

In addition to the required material, additional costs could include:

- land and right of way acquisition,
- engineering and environmental permitting and regulatory process, and
- unforeseen events during construction that require additional costs (referred to as 'construction contingencies').

The opinions on the typical cost range of intervention measures for coastal adaptation are based on experience, qualifications, and best judgment; have been prepared in accordance with acceptable principles and practices; are intended for comparative purposes only between the intervention measures in this guidebook; and are not intended for pricing of a specific project in a specific area.[8]

[8] Local market trends, non-competitive bidding situations, unforeseen labour and material adjustments, and other factors are beyond the control of CBCL Limited and as such CBCL Limited cannot warrant or guarantee that actual costs will not vary from the opinions provided. Further considerations on maintenance are provided in the next section.

2.6 Strategies to account for climate change projections

Climate change and sea level rise projections must be included in decisions regarding building of new infrastructure, or maintenance of existing infrastructure. The intended lifetime of the infrastructure is the primary consideration. Table 2.1 summarizes the basic engineering strategies to account for climate change. The strategies most applicable to each intervention option are listed in Table 2.2.

Coastal infrastructure typically has a lifetime of 20 to 50 years, depending on its nature or function. The effect of sea level rise on infrastructure is best dealt with using 'adaptive management'. Adaptive management refers to incremental upgrades to adapt infrastructure to changing conditions. Small incremental changes such as raising the structure or adding rock over a given cycle, typically 10 to 30 years, can be more financially manageable than over-building from the start. For existing infrastructure, a specific tool description is provided in the next section describing general maintenance, repair or replacement options.

> Planning for incremental upgrades on flexible infrastructure is a good way to deal with changing environmental conditions.

For more information on planning under conditions of uncertainty, refer to *Dynamic Adaptive Policy Pathways.*[9]

[9] Haasnoot, Marjolijn, et al. "Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world." Global environmental change 23.2 (2013): 485-498.

Table 2.1 Basic coastal engineering considerations for climate change

Lifetime / planning horizon	**Climate change impact on shoreline infrastructure**		**Engineering implications**	
	Coastal processes	Shoreline infrastructure	Existing infrastructure	New infrastructure
10 years	Dominated by natural variability, not climate change	None	Keep up with maintenance.	Use current design parameters.
20 years	Moderate increase in sea level and nearshore wave heights	Limited	Plan for an increase in maintenance and upgraded protection.	• Build away from shore and/or at high elevation if practical. • Plan for maintenance. • Use flexible design allowing for a gradual increase in protection level/elevation.
50 to 100 years	Significant increase in sea level and nearshore wave climate	Significant - flooding, erosion, storm damage to infrastructure	Consider mix of options: • Increase maintenance and protection • Raise structures • Managed retreat	

Table 2.2 Strategies to account for climate change projections

	Project with expected short-term lifespan (10 yrs.)	**Project with expected medium to long-term term lifespan (20 + yrs.)**
	Keep up with maintenance (existing infrastructure) or use current design parameters (new temporary infrastructure).	Build higher and stronger, preferably with an **adaptive management** strategy. This flexible design approach should allow for stepped increases in the protection level as sea level rises. This is generally more manageable financially, as opposed to building now for projected sea levels 100 years in the future.
Living shoreline/wetland		
Plant stabilization		
Dune restoration		
Beach nourishment		-
Perched beach	-	
Artificial reefs		
Engineered revetment	-	
Buried revetment	-	
Rip-rap armouring		
Groynes	-	
Shore attached breakwaters	-	
Detached breakwaters	-	
Retaining wall	-	
Seawall	-	
Dyke	-	
Scour protection		
Tide barrier/aboiteau	-	
Dredging		-
Dry flood proofing building	-	
Wet flood proofing building	-	
Raised infrastructure	-	
Floating building	-	
Stormwater management (drainage ditch, detainment pond, rain garden)		
Managed Retreat – Relocate infrastructure	-	

2.7 Guidance for design and implementation

Table 2.3 provides general guidance on the essential information and minimum professional expertise required for implementing each coastal intervention option. Assistance for these next steps can typically be provided by a combination of provincial government and engineering consultants if required. It is extremely important to note that for any coastal intervention a broad system understanding is essential when dealing with climate change impacts. The coastal area is very dynamic and any changes to a single location can have impacts in adjacent areas. Climate change adaptation should consider a "whole system" analysis, adaptive management, multi-disciplinary teams, innovation, and long-term planning for uncertainty.

Table 2.3 Typical information and expertise required for implementation of the coastal intervention options.

	Typically required													
	Information/ Data								**Professional Expertise**					
	Land topography	Marine bathymetry (i.e., water depths)	Erosion rates	Flood mapping	Extreme water levels	Wave heights	Extreme currents	Sediment transport	Civil engineer	Geotechnical engineer	Coastal engineer	Water resource	Marine/aquatic biologist	Landscape architects
Living shoreline/wetland	■	■	■	■	■	■	■				■		■	■
Plant stabilization	■		■		■	■							■	■
Dune restoration	■		■	■	■	■		■			■			■
Beach nourishment	■	■	■		■	■		■			■			■
Perched beach		■	■		■	■		■			■			■
Artificial reefs		■				■	■				■			■
Engineered revetment	■	■	■		■	■	■	■			■			
Buried revetment	■	■	■	■	■	■		■			■			
Rip-rap armouring	■	■	■		■	■	■	■			■			■
Groynes		■	■		■	■	■	■			■			
Shore attached breakwaters		■	■		■	■	■	■			■			
Detached breakwaters		■	■		■	■	■	■			■			
Retaining wall	■		■		■					■				
Seawall	■	■	■	■	■	■				■	■			
Dyke	■			■	■	■				■	■	■		
Scour protection	■	■			■	■	■	■	■					
Tide barrier/aboiteau	■	■		■	■	■	■			■	■	■		
Dredging	■		■	■		■	■		■	■	■			
Dry flood proofing building	■			■	■				■					
Wet flood proofing building	■			■	■				■					
Raised infrastructure	■			■	■				■					
Floating building	■			■	■				■					
Stormwater management (drainage ditch, detainment pond, rain garden)	■			■	■		■					■		■
Managed Retreat – Relocate infrastructure	■			■	■				■					■

Chapter 3: Inventory of Intervention Options

This section presents a number of intervention options for use in coastal climate change adaptation with relevance to adaptation in the Atlantic Provinces. Those interventions could be applied independently or as hybrid solutions, which combine nature-based approaches with traditional engineered coastal infrastructure, providing higher levels of protection from coastal hazards while simultaneously enhancing the resilience of both the infrastructure and the ecosystem. This information is for general education purposes, to help the reader evaluate the potential solutions suggested by the CLIMAtlantic web-based decision-support tool, *Coastal Adaptation Tool*.

Each community will be unique in its approach to adaptation at the coast. A combination of measures is often used to reach adaptation objectives, and many measures depend on the implementation of another or are more effective when combined. For example, dykes as a flood mitigation strategy are usually paired with engineered revetments to manage erosion or tide barriers (aboiteaux) and drainage ditches to enhance the dykes' flood mitigation ability.

The conceptual interventions were drawn from a review of the regional, national and international documentation, and organized into three categories: erosion mitigation, flood mitigation and tools that cover both flood and erosion mitigation. These tools were further classified into the five adaptation approaches: avoid, retreat, accommodate, protect, and procedural. Some of the intervention measures outlined in this document cover more than one of the adaptation approaches.

Another resource that characterizes coastlines and provides relevant management measures is the Coastal Hazard Wheel App, developed by UNEP-DHI, Deltares and COWI (2022) can be accessed using the following link: https://chw-app.coastalhazardwheel.org/.

3.1 Maintenance, repair, or replacement of existing infrastructure

Case 1: Structure is experiencing damage

The most suitable remediation of a damaged structure will depend on several factors, including, but not limited to, the following:

- Age and intended lifetime;
- Design criteria and climate conditions (e.g., anticipated sea level / wave climate / runoff);
- Construction material and method (flexible rock/sand vs. hard concrete);
- Type of damage (localized vs. general);
- Life-cycle costs (replace vs. repair).

While a site-specific engineering assessment would typically be required, the following general considerations provide initial guidance.

Coastal infrastructure typically has a lifetime of 20 to 50 years, depending on its nature or function. It is common to find ways to extend the lifetime of a particular structure through ongoing maintenance, such as replacing elements, raising it, or adding additional material like rock. In this context, the effect of sea level rise on infrastructure is best dealt with using 'adaptive management'. Adaptive management refers to incremental upgrades to adapt infrastructure to changing conditions. Smaller changes such as raising the structure over a given cycle, typically 10 to 30 years, can be more financially manageable.

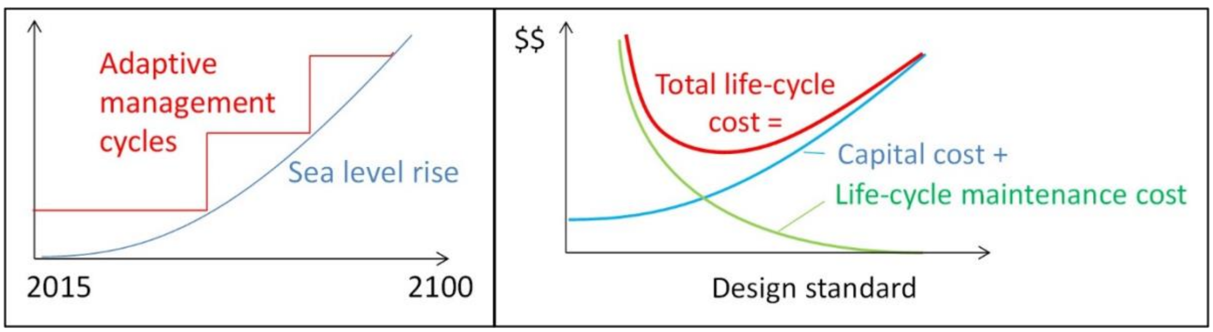

Figure 3.3 Adaptive management (left) and life-cycle cost analysis concept (right). Some intervention measures that cost a lot upfront have lower maintenance costs, while tools that are cheap upfront can have higher maintenance cost after. There is a 'sweet spot' somewhere in the middle. (Vincent Leys, CBCL Limited)

Table 3.1 Typical examples of coastal structures experiencing damage and potential remediation measures.

Type of structure	Potential damage experienced	Potential remediation measures
Armour rock structure	Initial damage, (e.g., a few rocks displaced from armour layer)	Monitor and maintain by replacing displaced rocks.
	Failure of the armour layer, such that the underlayers of filter or core rock became exposed	Analyze damage causes, re-design armour layer and slope for future wave and sea level rise conditions and re-build with larger rock and/or flatter slope.
	Armour layer destabilization due to scour	Install additional rock at base of structure for scour protection, and repair damaged section.
	Overtopping	Raise crest and/or build to a flatter slope.
Hybrid, (e.g., buried rock revetment)	Sand washed out; armour rock exposed	• Beach nourishment • Plant vegetation
	Post-construction sinkholes	Fill holes, preferably with coarse material.
	Overtopping	Raise crest and/or build to a flatter slope.
Non-flexible hard structure (e.g., seawall or wharf or retaining wall)	Overtopping	Raise crest and/or build to a flatter slope.
	Damage or failure from erosion	• Repair or replace. • Replace or combine with more flexible structure (e.g., rock, sand).
Beach or dune	Erosion	Sand nourishment, dune vegetation
Living shoreline	Erosion	Re-plant, add rock sill
Dyke	Erosion	Add rock protection, managed dyke realignment
	Overtopping	Raise crest
Culvert or bridge or aboiteau	Road washout	Re-design for higher capacity and replace with larger unit.
	Ice Jams causing flooding	Conduct study to evaluate risks and potential mitigation measures – could require upsizing structure.
	Erosion around structure and/or road	Repair damaged area, place larger riprap protection; consider redesign for higher capacity.
Coastal road or building	Repeated flooding	• Raise road/building. • Floodproof building with higher design flood level. • Build seawall/rock revetment. • Relocate road/building.
	Washout from wave action	• Build rock revetment or living shorelines (breakwaters and salt marsh) protection. • Relocate the road/building.

Note: also consider alternative measures (managed retreat or other) before undertaking significant maintenance.

Case 2: Structure is causing erosion or flooding damage

Coastal structures may cause unintended problems to other areas if the impacts on the coastal processes were not fully understood before construction. Problems can also occur due to conditions changing over time with sea level rise and/or increased precipitation. While a site-specific engineering assessment would typically be required, the following examples are provided for initial guidance. Removal of the structure causing damage should also be considered as a potential remediation measure for each case below.

Table 3.2 Typical examples of coastal structures causing damage and potential remediation measures.

Type of structure	Potential damage caused	Potential remediation measures
Hard shoreline structure e.g., seawall / rock revetment / groyne / breakwater	Blocks sand supply from eroding shoreline, which increases erosion down the coast, OR Interrupts natural sand transport	• Beach nourishment • Shorten, relocate landward or remove structure to allow naturally stable shoreline alignment.
Seawall	Erosion of shoreline on opposite bank due to reflection of wave energy	• Beach nourishment • Replace with shoreline treatment that better absorbs wave energy (e.g., flatter slope/more porous). • Relocate structure landward.
Dykes	Poor drainage of runoff	• Upgrade aboiteaux. • Install pumps. • Stormwater management
	Too close to river channel, causing flooding due to restricted floodplain	• Move dykes further away from channel to re-establish floodplain.
	Too close to river channel, causing erosion	• Managed retreat to allow more room for the river to naturally migrate/meander.
Aboiteau (tidal gate)	Submerged due to blockage by sedimentation, increasing flooding risks from extreme storm water volumes and sea level rise	• Maintenance dredging • Move structure downstream and raise its bottom elevation. • Design gate to allow some two-way flow to reduce sedimentation.
Storm water management infrastructure	Overflows / flooding	• Increase infiltration, storage and/or conveyance capacity. • Install pumps.

Note: also consider alternative measures (relocation or other) before undertaking significant maintenance.

3.2 Living shorelines (coastal wetlands and salt marsh restoration)

Salt marshes and coastal wetlands can maintain a naturally sustainable shoreline as sea levels rise, i.e., a shoreline where erosion and growth (sediment accumulation and vegetation) remain in balance.[10] Natural materials help provide short-term protection and, as the materials decompose, will encourage plant growth and shore stabilization. Re-establishing salt marshes and coastal wetlands reduce the impacts of flooding and erosion and strengthen the natural ecosystem.[11,12]

Planting appropriate vegetation may be required in the process of restoring salt marshes and coastal wetlands. If used in combination with other measures, such as engineered revetments and beach nourishment, coastal wetland restoration can allow communities to take back land that has previously been lost to the ocean (or flooded).[13]

For salt marsh restoration projects, emerging techniques such as thin-layer placement can help reduce costs and account for sea level rise. Thin-layer placement involves mimicking natural sediment deposition in tidal marshes by adding small amounts of sediment to the marsh and slowly increasing the elevation. Navigation dredging projects can be utilized to provide sediment over time, which can also significantly reduce creation costs of intertidal nature-based solutions.

Figure 3.4 Mahone Bay Living Shoreline Pilot, NS (Samantha Battaglia, Coastal Action, July 2022)

[10] Nicholls, R.J. & Klein, R.J.T. (2005). Climate change and coastal management on Europe's coast in Vermaat, J.E., Bouwer, L., Turner, R.K., Salomons, W. (Eds.). Managing European Coasts: Past, Present and future. (pp. 199-225). Berlin: Springer-Verlag
[11] 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 Centre for BC and submitted to Climate change Impacts and Adaptation Division, NRCan, AP040
[12] Wamsley, T.V., Cialone, M.A., Smith, J.M., Atkinson, J.H., Rosati, J.D. (2009). The potential of wetlands in reducing storm surge. Ocean Engineering. 37, 59–68, http://dx.doi.org/10.1016/j.oceaneng.2009.07.018
[13] Konisky, R.A., Burdick, D.M., Dionne, M., Neckles, H.A. (2006). A regional assessment of salt marsh restoration and monitoring in the Gulf of Maine. Restoration Ecology, 14(4). 516-525, DOI: 10.1111/j.1526-100X.2006.00163.x

Intervention Summary: Living Shorelines (Coastal Wetlands and Salt Marsh Restoration)		
Coastal Risk	Erosion and flooding	
Adaptive Response	Protect	
Grey to Green Spectrum (Grey, Green – Sediment Based, Green – Vegetation)	Green	
Cost ($ Low, $$ Medium, $$$ High)	$ to $$ (depends on wave exposure)	
Maximum Wave Exposure	Protected	
Sediment supply required?	Initial fill	
Ideal position in coastal profile (Nearshore, Foreshore, Backshore)	Foreshore/ backshore	
Protection (Good, Neutral, Negative/Causing Erosion or Flooding)	*Coast (above high tide)*	Neutral
	Natural tidal zone	Good
	Flood defence	Good
Impacts (Positive, Neutral, Negative)	*Downdrift beach*	Neutral
	Aesthetics	Positive
	Swimming safety	Neutral
Sustainability & preservation (enhances sustainability, neutral, not sustainable)	*Coastal morphology*	Enhances sustainability
	Habitat/ biodiversity	Enhances sustainability
Opportunities:	• Restores habitat for wildlife and fish spawning. • Increases water quality along the coast. • If managed well, wetlands can become an educational, recreational, and environmental asset to the community. • Long-term solution that addresses both flooding and erosion. • Wetlands can adapt to sea- level rise without maintenance (if the rate of sea level rise is not too rapid to keep pace). Increased buildup of sediments should allow the height of the wetland to rise with changes in sea level.	
Constraints:	• Not effective for exposed high wave energy areas, unless used in combination with nearshore breakwaters and sand fill. • A wetland restoration project may take a long time to complete depending on the scale of the project. • A large area is needed for restoration; this could be an issue in areas with high development potential. • Requires expertise, especially in locations where wetland restoration must be done by re-vegetating the shoreline with transplanted wetland plants. Also requires access to local nursery stock. • May require the acquisition of private land. This increases the upfront capital cost of restoration.	

3.3 Plant stabilization (or bio-engineered)

Planting vegetation is a natural and cost-effective option to stabilize dunes, sand beachheads, salt marshes, and cliffs or bluffs. However, care must be taken to choose the right plant types and planting locations that will give the most benefit. The plant roots will stabilize loose sediment or waterlogged soil to both prevent erosion and trap wind-blown sand (for building dunes). Plant stabilization can be reinforced by 'bio-engineered' products such as turf mats or coir logs as shown below. Plant stabilization is usually used along with other reinforcing protection at the foot of a slope including rock scour protection placed at the base of a slope, or the placement of sediment at the base of a slope so that storms are fed by the nourished sediment rather than the bluff itself (toe nourishment).

Figure 3.5 Installation of a turf reinforced mat with rock toe up to elevation of HW along coastal trail near Lawrencetown Beach, NS. It was infilled with hydraulically applied mulch (left), which was selected based on site conditions.

Intervention Summary: Plant or Bio Engineered Stabilization		
Coastal Risk	Erosion	
Adaptive Response	Protect	
Grey to Green Spectrum (Grey, Green – Sediment Based, Green – Vegetation)	Green – vegetation	
Cost ($ Low, $$ Medium, $$$ High)	$	
Maximum Wave Exposure	Protected	
Sediment supply required?	No	
Ideal position in coastal profile (Nearshore, Foreshore, Backshore)	Backshore	
Protection (Good, Neutral, Negative/Causing Erosion or Flooding)	*Coast (above high tide)*	Good
	Natural tidal zone	Good
	Flood defence	Neutral
Impacts (Positive, Neutral, Negative)	*Downdrift beach*	Neutral
	Aesthetics	Positive
	Swimming safety	Neutral
Sustainability & preservation (enhances sustainability, neutral, not sustainable)	*Coastal morphology*	Neutral
	Habitat/ biodiversity	Enhances sustainability
Opportunities:	• Cost effective solution. • Positive environmental solution for erosion. • Helps build dunes and stabilize bluffs, cliffs and salt marshes. • Aquatic plants can reduce wave energy and will naturally respond to sea level rise. • Once planted, it will require very little maintenance and will often regrow after extreme events.	
Constraints:	• Ineffective for high wave energy areas. • Using the wrong type of plants may be ineffective or choke out existing native vegetation—experts should be consulted for plant types. • Availability of suitable native plants from a local nursery. Seedlings require time to grow and need to be ordered in advance. • Increasing accessibility and abundance of Indigenous culturally significant and traditional plants and medicines.	

3.4 Dune restoration or stabilization (dune building)

Dunes are mounds of sand that act as a flexible buffer between the ocean and the upland. They protect the upland from both erosion and flooding. During storms, the base of the dunes may be eroded, giving extra sand to the ocean currents, and reducing erosion in neighbouring areas. Sand may also be transported inland to dunes by wind. Between storms, dunes are gradually built up again as vegetation or built structures trap windblown sand. These structures, such as dune fences, should not stop the natural movement and shifting of dunes.

Figure 3.6 Dune restoration during the construction of a buried revetment at Basin Head, PEI (Jody MacLeod, CBCL Limited)

Intervention Summary: Dune Restoration or Stabilization		
Coastal Risk	Erosion and flooding	
Adaptive response	Protect	
Grey to Green Spectrum (Grey, Green – Sediment Based, Green – Vegetation)	Green	
Cost ($ Low, $$ Medium, $$$ High)	$	
Maximum Wave Exposure	Exposed	
Sediment supply required?	Yes	
Ideal position in coastal profile (Nearshore, Foreshore, Backshore)	Backshore	
Protection (Good, Neutral, Negative/Causing Erosion or Flooding)	*Coast (above high tide)*	Good
	Natural tidal zone	Neutral
	Flood defence	Good
Impacts (Positive, Neutral, Negative)	*Downdrift beach*	Neutral
	Aesthetics	Positive
	Swimming safety	Neutral
Sustainability & preservation (enhances sustainability, neutral, not sustainable)	*Coastal morphology*	Neutral
	Habitat/ biodiversity	Neutral
Opportunities:	• Reduces erosion in neighbouring shoreline areas. • Reduces flooding and erosion for a target area. • Adds dune habitat to the coast that is very limited in Canada and is necessary for certain plant and animal species. • If well designed and managed dunes can be popular recreation areas.	
Constraints:	• Only suitable for sandy shorelines. • Does not reduce existing (‘background’) sand erosion rate and may require regular re-nourishment of sand. • Landward dune building, or expansion may require land acquisition. • Availability of appropriate local plants.	

3.5 Beach nourishment

Beach nourishment involves excavating sand from land or the ocean floor (dredging) and depositing it along the shoreline. Nourishment can be used on the backshore, foreshore, or on the beach itself. It does not prevent erosion but is used as an erosion response as sediment is added to the coastal system which decreases erosion from other parts of the coastline. It is commonly used along the Eastern Seaboard of the United States for storm protection. Beach nourishment must be applied to a large area to be effective. It must also be used with other erosion control techniques and requires regularly scheduled maintenance. Maintenance involves adding more sand every few years. Generally, beach nourishment is cheaper to install than hard structures, but more expensive to maintain. A thorough life-cycle analysis is required prior to implementation. The time a nourishment project will last in service (project life) varies greatly with the length of shore that is nourished. For example, doubling the shore length increases project life four times.

The profile of the beach, or the variation of the water depth from the shore to the offshore area, will depend on the type of sediment and wave climate of the area. For example, finer sands will have a flatter profile shape under wave action. Therefore, nourishing with coarse sand requires less material than if using fine sand. Constructing a groyne to prevent sediment loss into an inlet is a consideration when nourishing a beach on the downdrift end of a barrier beach near a tidal inlet. During the project planning phase, typical design values of 125 to 250 m^3 of sand per metre of shoreline can be used for 20 to 30 metres of added beach width.

Implementation of beach nourishment could cause initial disturbance to the existing ecosystem. The long-term impact on the ecosystem depends on its ability to recover between renourishment events.[14] For this reason, it is important to take a multidisciplinary, systems-based approach to ensure the nourishment strategy is compatible with the existing environment, as mentioned in *Chapter 1: Adaptation Approaches to Coastal Risk*.

Figure 3.7 Beach after nourishment at Pointe-du-Chêne Harbour (Vincent Leys, CBCL Limited)

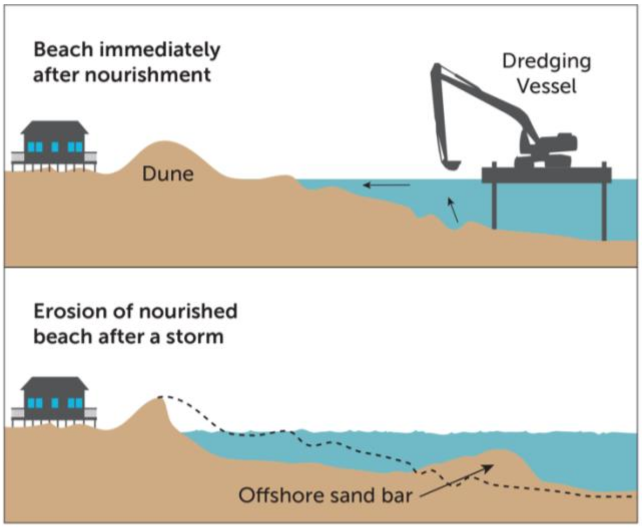

Figure 3.8 Beach nourishment diagram (after Vincent Leys, CBCL Limited)

[14] International Guidelines for Natural and Nature Based Features for Flood Risk Management (U.S Army Corps of Engineers, 2021)

INTERVENTION SUMMARY: BEACH NOURISHMENT		
COASTAL RISK	Erosion	
ADAPTIVE RESPONSE	Protect	
GREY TO GREEN SPECTRUM (GREY, GREEN – SEDIMENT BASED, GREEN – VEGETATION)	Green – sediment based	
COST ($ LOW, $$ MEDIUM, $$$ HIGH)	$$	
MAXIMUM WAVE EXPOSURE	Moderate	
SEDIMENT SUPPLY REQUIRED?	Yes	
IDEAL POSITION IN COASTAL PROFILE (NEARSHORE, FORESHORE, BACKSHORE)	Backshore	
PROTECTION (GOOD, NEUTRAL, NEGATIVE/CAUSING EROSION OR FLOODING)	*Coast (above high tide)*	Good
	Natural tidal zone	Good
	Flood defence	Neutral
IMPACTS (POSITIVE, NEUTRAL, NEGATIVE)	*Downdrift beach*	Positive
	Aesthetics	Positive
	Swimming safety	Neutral
SUSTAINABILITY & PRESERVATION (ENHANCES SUSTAINABILITY, NEUTRAL, NOT SUSTAINABLE)	*Coastal morphology*	Not sustainable
	Habitat/ biodiversity	Neutral
OPPORTUNITIES:	• Effectively mitigates storm damage. • Provides sand to the coastal circulation system. • Effective way to maintain beaches when used with other erosion prevention structures like groynes or breakwaters.	
CONSTRAINTS:	• Reliable sources of good quality sand required. • Does not reduce the amount of erosion that occurs naturally. • Requires regular and expensive maintenance. • Regulatory requirements.	

3.6 Perched beach (sill)

A perched beach can be created where the natural, or initial, profile of a beach comes too close to valuable infrastructure or property. Constructing a perched beach involves creating a barrier, or sill, of concrete or rock underwater and backfilling the structure with sand. This construction artificially advances the beach profile seaward. Perched beaches may be installed in front of seawalls to reduce the wave energy directly impacting the wall. The profile of the beach will depend on the type of sediment and wave climate of the beach. For example, finer sands will have a flatter profile shape under wave action.

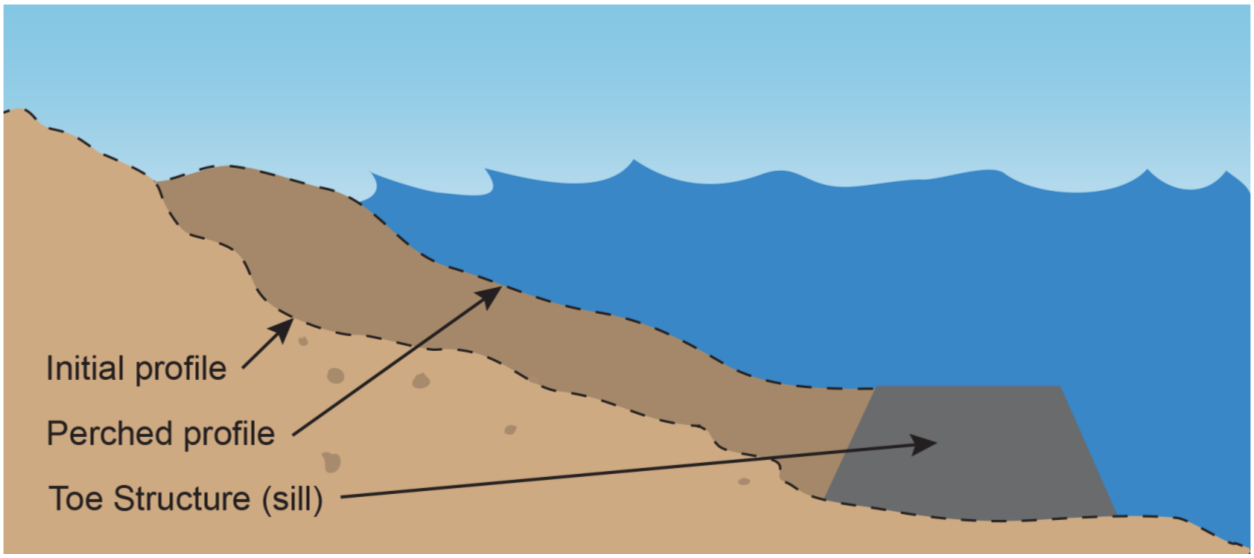

Figure 3.9 Perched beach depiction (Vincent Leys, CBCL Limited)

Intervention Summary: Perched Beach		
Coastal Risk	Erosion	
Adaptive Response	Protect	
Grey to Green Spectrum (Grey, Green – Sediment Based, Green – Vegetation)	Green – sediment based	
Cost ($ Low, $$ Medium, $$$ High)	$$	
Maximum Wave Exposure	Moderate	
Sediment supply required?	Yes	
Ideal position in coastal profile (Nearshore, Foreshore, Backshore)	Nearshore	
Protection (Good, Neutral, Negative/Causing Erosion or Flooding)	*Coast (above high tide)*	Neutral
	Natural tidal zone	Good
	Flood defence	Neutral
Impacts (Positive, Neutral, Negative)	*Downdrift beach*	Positive
	Aesthetics	Positive
	Swimming safety	Negative
Sustainability & preservation (enhances sustainability, neutral, not sustainable)	*Coastal morphology*	Negative
	Habitat/ biodiversity	Neutral
Opportunities:	• Reduces the amount of sand required for beach nourishment. • Decreases the maintenance costs for seawalls. • Creates beach areas for recreation and natural habitat on coasts with steep profiles.	
Constraints:	• Initial costs of installing a sill can be high. • Loss of sand over the sill during extreme storms is irreversible. • Not suitable for coasts with waves impacting the coast at an angle causing longshore sand transport. • If the sill is too high or low it can lead to significant erosion of the nourished beach sand.	

3.7 Artificial reefs

Artificial reefs can be made from a variety of different materials that are described below. The best designs attempt to mimic natural forms, use naturally occurring material, and help restore natural reef systems. Near shore reefs control beach erosion by reducing the wave energy hitting the beach. Lower wave energy allows waves to deposit sediment rather than erode the foreshore. The artificial reef provides protection immediately after installation. The level of shoreline protection will increase as oysters and other reef-building creatures inhabit the structure over the decades following installation.[15]

Concrete reef balls are molded hollow structures that range in size from a few pounds to 7,000 pounds. Steel triangular reef blocks are welded metal frames 5 feet wide and filled with oyster shells. The structures are usually lined or filled with native, local shellfish shells to kick start natural reef growth.[16]

Figure 3.10 Concrete reef balls (Paul Stern, 2014)

[15] Fodrie, F. J., Rodriguez, A. B., Baillie, C. J., Brodeur, M. C., Coleman, S. E., Gittman, R. K., ... & Lindquist, N. (2014). Classic paradigms in a novel environment: inserting food web and productivity lessons from rocky shores and saltmarshes into biogenic reef restoration. Journal of Applied Ecology, 51(5), 1314-1325.

[16] Harris, L. (2006). Artificial Reefs for Ecosystem Restoration and Coastal Erosion Protection with Aquaculture and Recreational Amenities. ASR Conference. Melbourne, FL, USA. Retrieved from http://www.artificialreef.com/reefball.org/album/%3D%3D%29%20Non-Geographic%20defined%20Photos/artificialreefscientificpapers/2006JulyLEHRBpaper.pdf

Intervention Summary: Artificial reefs		
Coastal Risk	Erosion	
Adaptive response	Protect	
Grey to Green Spectrum (Grey, Green – Sediment Based, Green – Vegetation)	Green-grey hybrid	
Cost ($ Low, $$ Medium, $$$ High)	$	
Maximum Wave Exposure	Moderate	
Sediment supply required?	No	
Ideal position in coastal profile (Nearshore, Foreshore, Backshore)	Nearshore	
Protection (Good, Neutral, Negative/Causing Erosion or Flooding)	*Coast (above high tide)*	Good
	Natural tidal zone	Good
	Flood defence	Neutral
Impacts (Positive, Neutral, Negative)	*Downdrift beach*	Neutral
	Aesthetics	Positive
	Swimming safety	Negative
Sustainability & preservation (enhances sustainability, neutral, not sustainable)	*Coastal morphology*	Negative
	Habitat/ biodiversity	Positive
Opportunities:	• Relatively cost effective. • Opportunities to increase habitat for local organisms. • Can be used as part of a Living Shoreline. • Will naturally increase in height as sea- level rises over long periods of time.	
Constraints:	• May partially or fully sink in areas with deep or unstable sediment. • Does not prevent flooding caused by sea-level rise but will help mitigate wave impact on the shore as water levels rise. • Navigability and coastal access may be affected as the reefs naturally expand both vertically and horizontally. • Placement of artificial reefs for erosion mitigation may not align with ideal placement for benthic (ocean floor) or fish habitat location.	

3.8 Revetments (engineered)

Engineered revetments can be made from rock, concrete panels, wood frames or corrosion-resistant wire-mesh filled with rock referred to as gabions. Revetments can be either exposed or buried structures.

Revetments can be combined with other protection structures such as when they are used at the foot of seawalls or to protect the base of dykes. Revetments are permeable structures that water can seep through, thereby dispersing wave energy. Rock revetments are generally built in two layers of rock placed on a core material and designed from the top down: the rock size, slope, and elevation of the primary (or outer) armour layer should be designed to resist forces from waves, ice and currents, and the size of rock used for the inner layer should be selected to prevent movement of material between the outer layer and the core. Gabions allow a smaller-sized stone to be used. Geotextiles (synthetic fabrics used to separate, filter and/or drain soils) can be used on top of the core material, however, they may reduce permeability and increase the rock size necessary for the structure to dissipate wave energy.

Figure 3.11 Revetment combined with beach stabilization structures at Fundy National Park, NB (Vincent Leys, CBCL Limited)

Intervention Summary: Revetments		
Coastal Risk	Flooding and erosion	
Adaptive response	Protect	
Grey to Green Spectrum (Grey, Green – Sediment Based, Green – Vegetation)	Green-grey hybrid	
Cost ($ Low, $$ Medium, $$$ High)	$$$	
Maximum Wave Exposure	Exposed	
Sediment supply required?	No	
Ideal position in coastal profile (Nearshore, Foreshore, Backshore)	Foreshore/backshore	
Protection (Good, Neutral, Negative/Causing Erosion or Flooding)	*Coast (above high tide)*	Good
	Natural tidal zone	Negative
	Flood defence	Neutral
Impacts (Positive, Neutral, Negative)	*Downdrift beach*	Negative
	Aesthetics	Negative
	Swimming safety	Neutral
Sustainability & preservation (enhances sustainability, neutral, not sustainable)	*Coastal morphology*	Not sustainable
	Habitat/ biodiversity	Neutral
Opportunities:	• Sloped, permeable revetments disperse wave energy. • Rock is a flexible construction material that can be cost effective in many regions. • Can be engineered for a long service life. • Commonly used tool with many successful examples.	
Constraints:	• Does not prevent flooding. • May cut off sediment supply and cause erosion in another location. • Steep revetments may cause erosion at the base of the revetment. • Cost of armour stone depends on the location of the project. • Maintenance is required (depending on design parameters) as nearshore breaking wave heights will increase with sea level rise.	

3.9 Buried revetment (artificial dune)

A buried revetment typically describes a rock slope or berm buried under a sand dune to create a barrier against flooding and erosion. The vegetated dune provides the first line of defense against wave action, and the buried revetment provides a last resort of protection during extreme storms if the dune gets eroded. Buried revetments should be paired with some form of beach or dune nourishment to be most effective. Gaps between rocks must be carefully filled during construction to minimise the chance of sinkholes developing between the buried rocks, an important consideration if the sand cover over the revetment is thin. Even if care is taken during initial construction, sinkholes are likely to form for some time after construction and some maintenance may be required.

Figure 3.12 Buried revetment at Dominion Beach, NS, two years after construction (top), and Lighthouse Beach, NS, six years after construction (Vincent Leys, CBCL Limited)

Intervention Summary: Buried Revetment		
Coastal Risk	Flooding and erosion	
Adaptive response	Protect	
Grey to Green Spectrum (Grey, Green – Sediment Based, Green – Vegetation)	Green-grey hybrid	
Cost ($ Low, $$ Medium, $$$ High)	$$$	
Maximum Wave Exposure	Exposed	
Sediment supply required?	No	
Ideal position in coastal profile (Nearshore, Foreshore, Backshore)	Foreshore/backshore	
Protection (Good, Neutral, Negative/Causing Erosion or Flooding)	*Coast (above high tide)*	Good
	Natural tidal zone	Negative
	Flood defence	Neutral
Impacts (Positive, Neutral, Negative)	*Downdrift beach*	Negative
	Aesthetics	Negative
	Swimming safety	Neutral
Sustainability & preservation (enhances sustainability, neutral, not sustainable)	*Coastal morphology*	Not sustainable
	Habitat/ biodiversity	Neutral
Opportunities:	• Scenery and habitat are improved. • Design includes a natural dune with the protective strength of a buried armour stone structure. • Less armour rock is needed compared with conventional rock revetments.	
Constraints:	• Armour rock is expensive, especially if not locally sourced. • Does not reduce background sand erosion rate (the amount of naturally occurring erosion at the site) and may require re-nourishment. • Risk of sink holes if gaps between rocks are not carefully filled during construction.	

3.10 Rip-rap armouring

Rip-rap armouring refers to loose rock or other material piled on the shoreline to reduce erosion. Material is usually dumped onto the shoreline from the end of a truck. This type of armour can be made from rock or other durable materials. It is a quick, easy, short-term fix and can be important during emergency situations. It is recommended to excavate a trench filled with stones at the base or 'toe' of the slope to prevent sliding of the material.

Figure 3.13 Rip-rap slope at Kingsport, NS, on the Bay of Fundy (Bruce Higgins, CBCL Limited)

Intervention Summary: Rip-Rap Armoring		
Coastal Risk	Erosion	
Adaptive response	Protect	
Grey to Green Spectrum (Grey, Green – Sediment Based, Green – Vegetation)	Grey approach / hard infrastructure	
Cost ($ Low, $$ Medium, $$$ High)	$$	
Regulatory Requirements	High	
Maximum Wave Exposure	Protected	
Sediment supply required?	No	
Ideal position in coastal profile (Nearshore, Foreshore, Backshore)	Foreshore/Backshore	
Protection (Good, Neutral, Negative/Causing Erosion or Flooding)	*Coast (above high tide)*	Good
	Natural tidal zone	Negative/Causing Erosion
	Flood defence	Neutral
Impacts (Positive, Neutral, Negative)	*Downdrift beach*	Negative
	Aesthetics	Negative
	Swimming safety	Neutral
Sustainability & preservation (enhances sustainability, neutral, not sustainable)	*Coastal morphology*	Negative
	Habitat/ biodiversity	Neutral
Opportunities:	• Can be a relatively quick way to prevent erosion in the short-term and in emergency situations. • Flexible construction (not subject to rigid material specifications and building codes) with easy maintenance (just add more rock).	
Constraints:	• Does not prevent flooding. • May cut off sediment supply and cause erosion in another area. • May cause erosion at the base of armouring. • Maintenance is required, especially in cases with limited engineering input.	

3.11 Groynes

Groynes are structures made from concrete, rock, or wood that extend into the water perpendicular to the shore. For areas where waves are not completely perpendicular to the shore ('oblique' wave climate), groins trap sand moving along the shoreline (littoral drift) and help grow the beach on the side of the structure with incoming sediment transport ('updrift'). When grouped together, in what is known as a groyne field, they can re-establish beaches along part of a coastline. The primary function of a groyne field is to trap sand, however, they must be pre-filled with new sand during construction to minimize erosion risks on the lee side of the structure (downdrift side). Thorough coastal studies are required for the design of groynes and for regulatory requirements. Groynes are prohibited in some areas. In the Atlantic Provinces, groynes are prohibited in New Brunswick (as of April 2015).

Figure 3.14 Basin Head groynes and beach along the tidal estuary (Vincent Leys, CBCL Limited)

INTERVENTION SUMMARY: GROYNES		
COASTAL RISK	Erosion	
ADAPTIVE RESPONSE	Protect	
GREY TO GREEN SPECTRUM (GREY, GREEN – SEDIMENT BASED, GREEN – VEGETATION)	Grey approach / hard infrastructure	
COST ($ LOW, $$ MEDIUM, $$$ HIGH)	$$ to $$$ (depends on wave exposure)	
REGULATORY REQUIREMENTS	High	
MAXIMUM WAVE EXPOSURE	Exposed (but only efficient for oblique waves)	
SEDIMENT SUPPLY REQUIRED?	Initial Fill	
IDEAL POSITION IN COASTAL PROFILE (NEARSHORE, FORESHORE, BACKSHORE)	Nearshore	
PROTECTION (GOOD, NEUTRAL, NEGATIVE/CAUSING EROSION OR FLOODING)	*Coast (above high tide)*	Good
	Natural tidal zone	Good
	Flood defence	Neutral
IMPACTS (POSITIVE, NEUTRAL, NEGATIVE)	*Downdrift beach*	Negative
	Aesthetics	Negative
	Swimming safety	Negative
SUSTAINABILITY & PRESERVATION (ENHANCES SUSTAINABILITY, NEUTRAL, NOT SUSTAINABLE)	*Coastal morphology*	Negative
	Habitat/ biodiversity	Neutral
OPPORTUNITIES:	• In areas with a strong longshore drift, groynes allow sand to build up on the updrift side (the side where sediment transport comes from). • Retain a wider beach by slowing down erosion of sand put in place for beach nourishment.	
CONSTRAINTS:	• Usefulness is restricted to sandy areas with longshore drift, such as beaches with an oblique wave climate. • Only reduces erosion on one side of the groyne (the updrift side). • Beach nourishment (dumping of sand) is required during the construction stage to minimize downdrift erosion. • May cause nearshore currents which can be hazardous to swimmers. • Maintenance is required (depending on design parameters), as nearshore breaking wave heights will increase with sea level rise.	

3.12 Shore-attached breakwaters (perpendicular)

Shore-attached breakwaters are long structures made from concrete, rock, or steel-sheet pile that extend out from the shore (as opposed to an offshore/detached breakwater that is not directly connected to the shore). They provide shelter to the shoreline from waves and can be designed to increase sediment build-up in desired locations. They are also referred to as jetties when used for navigation purposes: for example, to increase tidal current outflows at a tidal inlet. Attached breakwaters may also be curved at the end and act as artificial headlands (ridges of hard material extending out from land into the sea) to retain a beach. Thorough coastal studies are required for their design and regulatory requirements.

Figure 3.15 Beach stabilization breakwaters at Fundy National Park, NB (Vincent Leys, CBCL Limited)

Intervention Summary: Shore-Attached Breakwaters		
Coastal Risk	Erosion and Flooding*	
Adaptive Response	Protect	
Grey to Green Spectrum (Grey, Green – Sediment Based, Green – Vegetation)	Grey approach / hard infrastructure	
Cost ($ Low, $$ Medium, $$$ High)	$$$	
Regulatory Requirements	High	
Maximum Wave Exposure	Exposed (but only efficient for oblique waves, or waves that approach the beach at an angle)	
Sediment supply required?	Initial Fill	
Ideal position in coastal profile (Nearshore, Foreshore, Backshore)	Nearshore	
Protection (Good, Neutral, Negative/Causing Erosion or Flooding)	*Coast (above high tide)*	Good
	Natural tidal zone	Good
	Flood defence	Neutral
Impacts (Positive, Neutral, Negative)	*Downdrift beach*	Negative
	Aesthetics	Negative
	Swimming safety	Negative
Sustainability & preservation (enhances sustainability, neutral, not sustainable)	*Coastal morphology*	Negative
	Habitat/ biodiversity	Neutral
Opportunities:	• Reduces wave energy and shoreline erosion in the downdrift side relative to sediment transport direction. • Encourages beach growth on one side of the structure (its updrift side). • Reduces sedimentation in navigation channels in its lee (downdrift side). • Offers some flood protection if the main flooding mechanism is wave overtopping	
Constraints:	• Wave dissipation effects may decrease with distance away from structure. • May cause erosion in other areas (downdrift) along straight sandy shorelines. • May cause nearshore currents which are hazardous for swimmers. • Expensive construction costs. • Maintenance is required (depending on design parameters) as nearshore breaking wave heights will increase with sea level rise.	

**Can reduce flooding due to wave overtopping*.

3.13 Detached Breakwaters

Detached breakwaters are structures generally made from concrete or rock that are built parallel to the shore and within the littoral zone (the zone of active longshore sediment transport, which generally corresponds to the surf zone during storms). They are designed to provide shelter from waves to reduce erosion of the shoreline and can be designed to increase sediment build-up in desired locations. Detached breakwaters are generally located between half and twice the distance from the shore as the width of the littoral zone. For example, if the littoral zone is 100 metres wide, the breakwater would be between 50 and 200 metres from the shore. When these structures are within half the distance of the littoral zone width from the shore they are referred to as “beach breakwaters”. Thorough coastal studies are required for the design of nearshore breakwaters and regulatory requirements.


Figure 3.16 Breakwater constructed to mitigate erosion at West Point, PEI (Vincent Leys, CBCL Limited)

INTERVENTION SUMMARY: DETACHED BREAKWATERS		
COASTAL RISK	Erosion and Flooding*	
ADAPTIVE RESPONSE	Protect	
GREY TO GREEN SPECTRUM (GREY, GREEN – SEDIMENT BASED, GREEN – VEGETATION)	Grey approach / hard infrastructure	
COST ($ LOW, $$ MEDIUM, $$$ HIGH)	$$$	
REGULATORY REQUIREMENTS	High	
MAXIMUM WAVE EXPOSURE	Exposed	
SEDIMENT SUPPLY REQUIRED?	Initial Fill	
IDEAL POSITION IN COASTAL PROFILE (NEARSHORE, FORESHORE, BACKSHORE)	Nearshore	
PROTECTION (GOOD, NEUTRAL, NEGATIVE/CAUSING EROSION OR FLOODING)	*Coast (above high tide)*	Good
	Natural tidal zone	Good
	Flood defence	Neutral
IMPACTS (POSITIVE, NEUTRAL, NEGATIVE)	*Downdrift beach*	Negative
	Aesthetics	Negative
	Swimming safety	Negative
SUSTAINABILITY & PRESERVATION (ENHANCES SUSTAINABILITY, NEUTRAL, NOT SUSTAINABLE)	*Coastal morphology*	Negative
	Habitat/ biodiversity	Neutral
OPPORTUNITIES:	• Reduces wave energy and shoreline erosion. • Promotes beach build-up between the shore and the breakwater. • Littoral transport is modified in a smoother manner than for a shore-perpendicular structure, causing less downdrift shoreline impacts.	
CONSTRAINTS:	• Can be very expensive to construct and requires marine equipment. • Maintenance is required (depending on design parameters) as nearshore breaking wave heights will increase with sea level rise. • May require pre-filling with sand to minimize downdrift erosion risks. • May cause nearshore currents which are hazardous to swimmers.	

**Can reduce flooding that occurs as a result of wave overtopping*.

3.14 Retaining walls

Retaining walls are usually made from concrete blocks, timber, steel sheet pile, or stone contained in wire mesh also known as gabions. The primary purpose of a retaining wall is to prevent land behind the wall from sliding into the sea. Retaining walls should be used with the support of other measures (to be selected according to the characteristics of the site).
Using them alone is limited to areas that do not experience significant wave action. For instance, retaining walls are sometimes combined with armour stone at the base of the structure to reduce the impact of erosion. The design must include a means for seaward drainage of inland runoff through the wall.

Figure 3.17 Retaining walls made of wire-mesh baskets or 'gabions' (left) and timber (right).

Intervention Summary: Retaining Walls		
Coastal Risk	Erosion	
Adaptive response	Protect	
Grey to Green Spectrum (Grey, Green – Sediment Based, Green – Vegetation)	Grey	
Cost ($ Low, $$ Medium, $$$ High)	$$	
Maximum Wave Exposure	Protected	
Sediment supply required?	No	
Ideal position in coastal profile (Nearshore, Foreshore, Backshore)	Backshore	
Protection (Good, Neutral, Negative/Causing Erosion or Flooding)	*Coast (above high tide)*	Good
	Natural tidal zone	Neutral
	Flood defence	Neutral
Impacts (Positive, Neutral, Negative)	*Downdrift beach*	Neutral
	Aesthetics	Negative
	Swimming safety	Neutral
Sustainability & preservation (enhances sustainability, neutral, not sustainable)	*Coastal morphology*	Not sustainable
	Habitat/ biodiversity	Not sustainable
Opportunities:	• Relatively cost-effective to construct. • A good alternative to seawalls in protected coves. • Prevents unstable land from sliding into the sea, especially if combined with bluff drainage.	
Constraints:	• Lack flexibility which hinders regular maintenance (for example, a collapsing wall needs full replacement). • Not appropriate for areas exposed to waves with high scour potential.	

3.15 Seawall

Seawalls are structural barriers between the ocean and the land and are designed to resist the full force of waves and storm surge. They are usually made of non-flexible materials such as concrete, steel, or timber and can be designed with a variety of profile shapes. They prevent both flooding and erosion and are generally used for built-up areas that have limited land available for other adaptation solutions. Seawall design must include a means for inland water to drain through the wall.

Key principles for ecologically sound seawalls:

1. Decide if a seawall is needed or if other more environmentally favourable options could be used. Other options may include native vegetation and temporary wave barriers.
2. Maximise the use of native estuarine vegetation in the structure.
3. Maximise habitat diversity by increasing surface roughness and texture and incorporating microhabitats such as pools, crevices, boulders and ledges.
4. Create low-sloping seawalls or incorporate changes of slope to maximise habitat surface area.

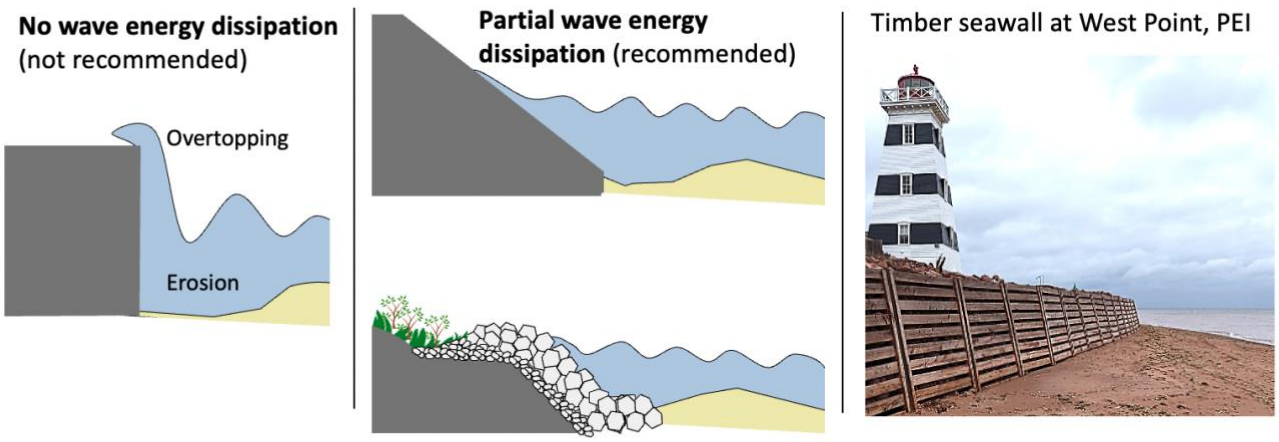

Figure 3.18 Examples of seawall concepts (left and center) and local example of a seawall (right) (Vincent Leys, CBCL Limited)

Intervention Summary: Seawall		
Coastal Risk	Erosion and flooding	
Adaptive Response	Protect	
Grey to Green Spectrum (Grey, Green – Sediment Based, Green – Vegetation)	Grey	
Cost ($ Low, $$ Medium, $$$ High)	$$$	
Maximum Wave Exposure	Exposed	
Sediment supply required?	Yes, initial fill	
Ideal position in coastal profile (Nearshore, Foreshore, Backshore)	Backshore	
Protection (Good, Neutral, Negative/Causing Erosion or Flooding)	*Coast (above high tide)*	Good
	Natural tidal zone	Negative
	Flood defence	Good
Impacts (Positive, Neutral, Negative)	*Downdrift beach*	Negative
	Aesthetics	Negative
	Swimming safety	Neutral
Sustainability & preservation (enhances sustainability, neutral, not sustainable)	*Coastal morphology*	Unsustainable
	Habitat/ biodiversity	Neutral
Opportunities:	• Requires little space and is useful when space for other protection tools is limited. • Mitigates both flooding and erosion of a built shoreline. • Protects valuable infrastructure/ important assets at risk.	
Constraints:	• Scour and beach erosion will occur around a seawall that does not properly absorb wave energy. • Regular maintenance may be difficult and a collapsing wall needs to be fully replaced. • Decreases the release of sediment from the protected area behind the wall, which may increase erosion in surrounding areas. • Reduces beach access for the public if the wall is steep and/or the beach erodes.	

3.16 Dykes

A dyke is a linear structure that runs along the coast and is usually constructed from compacted earth. Dykes prevent the flooding of coastal lowlands during extreme high tides and storm events. They have a more gradual incline on the waterside to reduce the impact of waves. Armouring may be required in the area exposed to waves in order to reduce erosion. Dykes often require some form of one-way culvert, or aboiteau to allow the lowlands to drain during low tide but prevent seawater from coming in during high tide. The culvert, or aboiteau must be maintained regularly to make sure it does not become blocked or malfunction. If water levels are likely to build up behind the dyke due to sustained high river flows, a pumping station may be needed to relieve flood risks of inland flooding on the landward side of the dyke.

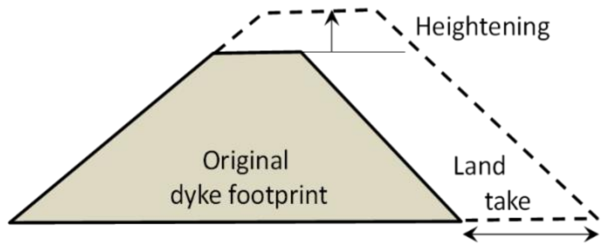

Figure 3.19 Storm impacts at Avonport dyke (left) and representation of land take implications of dyke heightening (right) (Left – Van Proosdij;[17] right – Vincent Leys, CBCL Limited)

[17] Van Proosdij, D., & Baker G. (2007). Intertidal Morphodynamics of the Avon River Estuary. Final report submitted to the Nova Scotia Department of Transportation and Public Works (NSTPW). Department of Geography, Saint Mary's University, 30 September 2007

INTERVENTION SUMMARY: DYKES		
COASTAL RISK	Flooding	
ADAPTIVE RESPONSE	Protect	
GREY TO GREEN SPECTRUM (GREY, GREEN – SEDIMENT BASED, GREEN – VEGETATION)	Grey	
COST ($ LOW, $$ MEDIUM, $$$ HIGH)	$$$	
MAXIMUM WAVE EXPOSURE	Exposed	
SEDIMENT SUPPLY REQUIRED?	No	
IDEAL POSITION IN COASTAL PROFILE (NEARSHORE, FORESHORE, BACKSHORE)	Foreshore	
PROTECTION (GOOD, NEUTRAL, NEGATIVE/CAUSING EROSION OR FLOODING)	*Coast (above high tide)*	Neutral
	Natural tidal zone	Neutral
	Flood defence	Good
IMPACTS (POSITIVE, NEUTRAL, NEGATIVE)	*Downdrift beach*	Neutral
	Aesthetics	Negative
	Swimming safety	Neutral
SUSTAINABILITY & PRESERVATION (ENHANCES SUSTAINABILITY, NEUTRAL, NOT SUSTAINABLE)	*Coastal morphology*	Neutral
	Habitat/ biodiversity	Not sustainable
OPPORTUNITIES:	• Prevents flooding of lowland coastal areas. • Slope on the waterside dissipates wave energy better than vertical structures. • Can be a long-term solution to flooding if it is effectively maintained. • Generally, the least expensive hard defense to use when the value of coastal land is low and the area is large.	
CONSTRAINTS:	• Requires a significant land area. • Heightening requires extra land in the back of the dyke (‘land take’). • Thorough coastal studies are required for design and regulatory requirements. • Results in a loss of the intertidal zone. • Sourcing appropriate material can add significant cost if not locally available.	

3.17 Scour protection

Scour protection prevents erosion (scouring) at the base of buildings, bridge piers, causeways, seawalls, dykes, or vegetated bluffs. It is commonly made of rock and is sometimes made of concrete or wood. The usual recommendation is to place materials in a dug-up trench to prevent material from sliding.

Figure 3.20 Scour protection at Cheticamp Bridge Piers using rock (left), and long tidal Shubenacadie River, NS (middle and right) using rock-filled gabion mats.

Intervention Summary: Scour Protection		
Coastal Risk	Erosion	
Adaptive response	Protect	
Grey to Green Spectrum (Grey, Green – Sediment Based, Green – Vegetation)	Grey	
Cost ($ Low, $$ Medium, $$$ High)	$$	
Maximum Wave Exposure	N/A	
Sediment supply required?	No	
Ideal position in coastal profile (Nearshore, Foreshore, Backshore)	Foreshore	
Protection (Good, Neutral, Negative/Causing Erosion or Flooding)	*Coast (above high tide)*	Good
	Natural tidal zone	Good
	Flood defence	Neutral
Impacts (Positive, Neutral, Negative)	*Downdrift beach*	Negative
	Aesthetics	Negative
	Swimming safety	Neutral
Sustainability & preservation (enhances sustainability, neutral, not sustainable)	*Coastal morphology*	Not sustainable
	Habitat/ biodiversity	Neutral
Opportunities:	• Cost-effective way to protect weak points on other, more expensive, flood and erosion control structures. • Only needs to be applied at key points. • Can be used for most coastal types. • Flexible construction with easy maintenance (just add more rock).	
Constraints:	• Scour protection should be applied for localized scour only. • Limited effect on coastal erosion. It does not deal with larger scale erosion or flooding. • May cause increased erosion in surrounding areas. • Maintenance is required (depending on design parameters) as the intensity of extreme events increases.	

3.18 Tide barriers/aboiteaux

Tidal or storm surge barriers are moveable barriers or gates that are closed to prevent flooding when extreme water levels or storm surges are forecast. They can also be constructed near the entrance of river estuaries and tidal inlets to reduce the impact of storm surge on these areas. Small scale barriers such as one-way culverts, or aboiteaux, allow inland runoff to drain from the lowlands behind a structure during low tide and prevent seawater from coming in during high tide. An aboiteau must be maintained regularly to ensure it does not malfunction or become blocked. Thorough coastal studies are required for the design and regulatory requirements for this infrastructure.

Figure 3.21 Aboiteau in LaPlanche, NS (Suvir Pursnani, CBCL Limited)

Intervention Summary: Tide Barriers/Aboiteaux		
Coastal Risk	Flooding	
Adaptive response	Protect	
Grey to Green Spectrum (Grey, Green – Sediment Based, Green – Vegetation)	Grey	
Cost ($ Low, $$ Medium, $$$ High)	$$$	
Maximum Wave Exposure	Moderate	
Sediment supply required?	No	
Ideal position in coastal profile (Nearshore, Foreshore, Backshore)	Foreshore	
Protection (Good, Neutral, Negative/Causing Erosion or Flooding)	*Coast (above high tide)*	Good
	Natural tidal zone	Neutral
	Flood defence	Good
Impacts (Positive, Neutral, Negative)	*Downdrift beach*	Neutral
	Aesthetics	Neutral
	Swimming safety	Neutral
Sustainability & preservation (enhances sustainability, neutral, not sustainable)	*Coastal morphology*	Neutral
	Habitat/ biodiversity	Not sustainable
Opportunities:	• The tidal gate allows for the closure of estuary mouths to prevent storm surge flood during extreme coastal storms. • The aboiteau allows river drainage during low tide to prevent the backing up of the river.	
Constraints:	• Can be very expensive depending on the size. • Results in intertidal habitat loss. • Requires regular maintenance. • Inland flooding would still occur when waters cannot be drained during high tide.	

3.19 Dredging

Dredging is the act of digging up the bottom of a channel to remove sediment that has built up in an estuary or harbour mouth. Dredging is usually used to keep channels open for boat navigation. Dredging can also provide important natural flushing of lagoons and prevent flooding at the point where a potential storm surge could push into a river. A storm surge can potentially move sediment into the river channel. The accumulated sediment could block water flow, or increase the risk of ice jams, which would in turn cause upstream flooding. Thorough coastal studies are required to design a dredged channel and to meet regulatory requirements.

Figure 3.22 Example of a dredging project from a small-scale channel mechanical excavation in Salmon River, NS (Graeme Matheson, Saint Mary's University)

<table>
<tr><th colspan="3">INTERVENTION SUMMARY: DREDGING</th></tr>
<tr><td>COASTAL RISK</td><td colspan="2">Flooding</td></tr>
<tr><td>ADAPTIVE RESPONSE</td><td colspan="2">Accommodate</td></tr>
<tr><td>GREY TO GREEN SPECTRUM
(GREY, GREEN – SEDIMENT BASED, GREEN – VEGETATION)</td><td colspan="2">Green – sediment based</td></tr>
<tr><td>COST
($ LOW, $$ MEDIUM, $$$ HIGH)</td><td colspan="2">$$$</td></tr>
<tr><td>MAXIMUM WAVE EXPOSURE</td><td colspan="2">Protected</td></tr>
<tr><td>SEDIMENT SUPPLY REQUIRED?</td><td colspan="2">Natural background supply</td></tr>
<tr><td>IDEAL POSITION IN COASTAL PROFILE
(NEARSHORE, FORESHORE, BACKSHORE)</td><td colspan="2">Foreshore</td></tr>
<tr><td rowspan="3">PROTECTION
(GOOD, NEUTRAL, NEGATIVE/CAUSING EROSION OR FLOODING)</td><td>Coast (above high tide)</td><td>Neutral</td></tr>
<tr><td>Natural tidal zone</td><td>Negative</td></tr>
<tr><td>Flood defence</td><td>Good</td></tr>
<tr><td rowspan="3">IMPACTS
(POSITIVE, NEUTRAL, NEGATIVE)</td><td>Downdrift beach</td><td>Negative</td></tr>
<tr><td>Aesthetics</td><td>Negative</td></tr>
<tr><td>Swimming safety</td><td>Neutral</td></tr>
<tr><td rowspan="2">SUSTAINABILITY & PRESERVATION
(ENHANCES SUSTAINABILITY, NEUTRAL, NOT SUSTAINABLE)</td><td>Coastal morphology</td><td>Neutral</td></tr>
<tr><td>Habitat/ biodiversity</td><td>Not sustainable</td></tr>
<tr><td>OPPORTUNITIES:</td><td colspan="2">• Effective if the dredging significantly increases the storage volume of flood water.
• May reduce river flooding in estuaries.
• Increases boat navigation clearance.
• Dredged sediment may be suitable material for other interventions such as beach nourishment or dyke maintenance.</td></tr>
<tr><td>CONSTRAINTS:</td><td colspan="2">• Does not prevent (and may increase) erosion.
• Not suitable if the floodplain is large relative to the waterway channel. In this case, the increase in the waterway's storage volume is minimal relative to the total flood discharge.
• Requires maintenance dredging if there is a regular natural supply of sediment.
• Disrupts the natural equilibrium between erosion and deposition.</td></tr>
</table>

3.20 Floodwalls/dry flood proofing

Floodwalls are used primarily in high value built up areas where other coastal protection or management options are limited, or when individual property owners want to protect their assets beyond whatever measures are already in place. The flood walls are usually made of concrete or are earth mounds. Their purpose is to enclose a property to prevent floodwater or storm surge from impacting the more valuable structures within. Dry flood proofing can also involve applying protective (waterproof) coatings to the structures that prevent water from penetrating the structure. These are not primary protection strategies and should only be considered as back up for emergency events.[18,19,20] Technical information and codes for flood-resistant buildings can be found in the *Guide for Design of Flood-Resistant Buildings*[21] *and Guidelines for Improving Flood-Resistance for Existing Buildings*[22] by the National Research Council of Canada (2021).

Figure 3.23 Schematic diagram showing dry flood proofing

[18] FEMA (Federal Emergency Management Agency). (2010). Wet Floodproofing. Washington DC: US Dept. of Homeland Security.
[19] Southern Tier Central Regional Planning & Development Board (STC-RPDB). (2010).
[20] FEMA (Federal Emergency Management Agency). (2007). Selecting Appropriate Mitigation Measures for Floodprone Structures. Washington DC: US Department of Homeland Security. Retrieved from www.fema.gov/library/viewRecord.do?id=2737
[21] Coulbourne, W., D.L. Kriebel, R. L. Behm, K.K. McKenna (2021) Guide for design of flood-resistant buildings. National Research Council of Canada. NRC Contract No. 930582. Accessed at: https://nrc-publications.canada.ca/eng/view/ft/?id=96b3275c-b731-4fa6-847e-e2a9a0f080d8
[22] Behm, R.L., W.L. Coulbourne, D.L. Kriebel, K.K. McKenna (2021) Guidelines for Improving Flood-resistance for Existing Buildings.National Research Council of Canada. NRC Contract No. 930582. Accessed at: https://nrc-publications.canada.ca/eng/view/ft/?id=c3b54b84-2a25-4e7e-ba3e-01c80378f086

INTERVENTION SUMMARY: FLOODWALLS/ DRY FLOOD PROOFING		
COASTAL RISK	Flooding	
ADAPTIVE RESPONSE	Protect	
GREY TO GREEN SPECTRUM (GREY, GREEN – SEDIMENT BASED, GREEN – VEGETATION)	Grey	
COST ($ LOW, $$ MEDIUM, $$$ HIGH)	$$$	
MAXIMUM WAVE EXPOSURE	Protected	
SEDIMENT SUPPLY REQUIRED?	No	
IDEAL POSITION IN COASTAL PROFILE (NEARSHORE, FORESHORE, BACKSHORE)	Backshore	
PROTECTION (GOOD, NEUTRAL, NEGATIVE/CAUSING EROSION OR FLOODING)	*Coast (above high tide)*	Neutral
	Natural tidal zone	Neutral
	Flood defence	Good
IMPACTS (POSITIVE, NEUTRAL, NEGATIVE)	*Downdrift beach*	Neutral
	Aesthetics	Neutral
	Swimming safety	Neutral
SUSTAINABILITY & PRESERVATION (ENHANCES SUSTAINABILITY, NEUTRAL, NOT SUSTAINABLE)	*Coastal morphology*	Neutral
	Habitat/ biodiversity	Neutral
OPPORTUNITIES:	• Suitable for most coastal types. • Does not require the removal of buildings. • Tool is easily customized to the specific site and flooding issues. • Can have movable sections to increase protection during extreme events. • A quick short-term solution that can be used to protect vital buildings until another solution is available or necessary funding is secured.	
CONSTRAINTS:	• Access to the structure is reduced during flood events. • May increase flooding and erosion for surrounding properties. • Temporary solution in the context of sea-level rise. If not properly designed it may trap flood water between the building and the floodwall during a breach or overtopping event.	

3.21 Wet flood proofing buildings

Wet flood proofing accommodates the possibility of flooding into the structure. This type of building technique is only applicable for building levels that are not used for residential space. It is best used for parking structures and storage of goods that would not be damaged by water. This technique allows water to flow in and out of the lower level of the buildings. Significant cleanup will often still be necessary after a flood.[23,24,25] Technical information and codes for flood-resistant buildings can be found in the *Guide for Design of Flood-Resistant Buildings*[26] *and Guidelines for Improving Flood-Resistance for Existing Buildings*[27] by the National Research Council of Canada (2021).

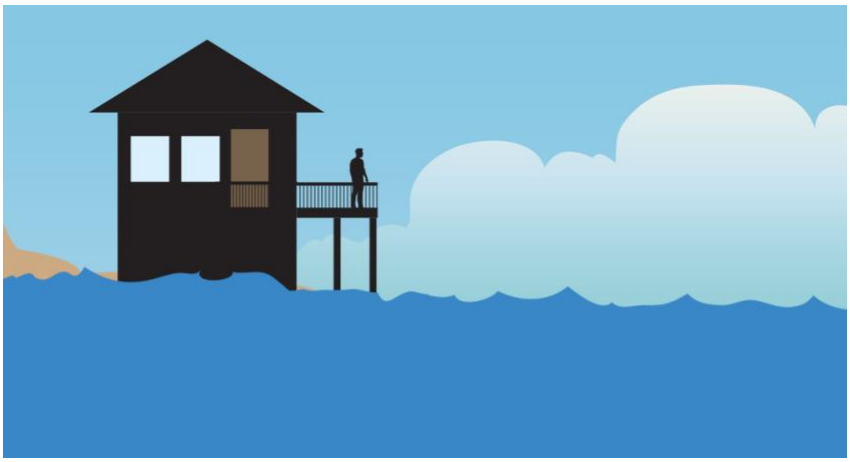

Figure 3.24 Schematic diagram showing wet flood proofing, lower levels 'permit' flooding

[23] FEMA (Federal Emergency Management Agency). (2009). Homeowner's Guide to Retrofitting. Washington DC: Dept. of Homeland Security. Retrieved from http://www.fema.gov/hazard/map/firm.shtm
[24] Southern Tier Central Regional Planning & Development Board (STC-RPDB), 2010
[25] FEMA (Federal Emergency Management Agency). (2007). Selecting Appropriate Mitigation Measures for Floodprone Structures. Washington DC: US Department of Homeland Security. Retrieved from www.fema.gov/library/viewRecord.do?id=2737
[26] Coulbourne, W., D.L. Kriebel, R. L. Behm, K.K. McKenna (2021) Guide for design of flood-resistant buildings. National Research Council of Canada. NRC Contract No. 930582. Accessed at: https://nrc-publications.canada.ca/eng/view/ft/?id=96b3275c-b731-4fa6-847e-e2a9a0f080d8
[27] Behm, R.L., W.L. Coulbourne, D.L. Kriebel, K.K. McKenna (2021) Guidelines for Improving Flood-resistance for Existing Buildings.National Research Council of Canada. NRC Contract No. 930582. Accessed at: https://nrc-publications.canada.ca/eng/view/ft/?id=c3b54b84-2a25-4e7e-ba3e-01c80378f086

INTERVENTION SUMMARY: WET FLOOD PROOFING BUILDINGS		
COASTAL RISK	Flooding	
ADAPTIVE RESPONSE	Accommodate	
GREY TO GREEN SPECTRUM (GREY, GREEN – SEDIMENT BASED, GREEN – VEGETATION)	Grey	
COST ($ LOW, $$ MEDIUM, $$$ HIGH)	$$$	
MAXIMUM WAVE EXPOSURE	Protected	
SEDIMENT SUPPLY REQUIRED?	No	
IDEAL POSITION IN COASTAL PROFILE (NEARSHORE, FORESHORE, BACKSHORE)	Backshore	
PROTECTION (GOOD, NEUTRAL, NEGATIVE/CAUSING EROSION OR FLOODING)	*Coast (above high tide)*	Neutral
	Natural tidal zone	Neutral
	Flood defence	Good
IMPACTS (POSITIVE, NEUTRAL, NEGATIVE)	*Downdrift beach*	Neutral
	Aesthetics	Neutral
	Swimming safety	Neutral
SUSTAINABILITY & PRESERVATION (ENHANCES SUSTAINABILITY, NEUTRAL, NOT SUSTAINABLE)	*Coastal morphology*	Neutral
	Habitat/ biodiversity	Neutral
OPPORTUNITIES:	• Suitable for most coastal types. • Allows for certain uses such as parking in areas that would otherwise be unsuitable for development. • Can be a cost-effective alternative to dry flood proofing structures or raising buildings. • Very limited environmental impacts. • More affordable than construction of elaborate flood protection works such as seawalls and dyke systems.	
CONSTRAINTS:	• Access to the structure is limited during flood events. • Reduces flooding impact on the structure, but does not protect the building from flooding and erosion. • Provides a temporary solution in the context of sea-level rise. • Requires cleanup and maintenance after floods.	

3.22 Raised infrastructure

Raising infrastructure is another form of wet flood proofing, but one that specifically involves raising the critical use areas of a building (or other infrastructure) above flood levels. A building's elevation can be increased through the use of stilts or raised foundations. Stilts create non-living space under the building such as a garage or patio area. Another way to increase a building's elevation is to increase the height of the land with fill before the building is constructed. It is usually easier to build a brand-new raised building than to raise an existing building. Building code regulations may restrict the use of this adaptation technique. The principle can also be used to adapt vital infrastructure such as utilities and roads. Technical information and codes for flood-resistant buildings can be found in the *Guide for Design of Flood-Resistant Buildings*[28] *and Guidelines for Improving Flood-Resistance for Existing Buildings*[29] by the National Research Council of Canada (2021).

Figure 3.25 Schematic showing wet flood proofing

Figure 3.26 A multipoint foundation spreading the weight of a building over a wide area, allowing the structure to be more adaptable (Triodetic Multipoint Foundations)[30]

[28] Coulbourne, W., D.L. Kriebel, R. L. Behm, K.K. McKenna (2021) Guide for design of flood-resistant buildings. National Research Council of Canada. NRC Contract No. 930582. Accessed at: https://nrc-publications.canada.ca/eng/view/ft/?id=96b3275c-b731-4fa6-847e-e2a9a0f080d8

[29] Behm, R.L., W.L. Coulbourne, D.L. Kriebel, K.K. McKenna (2021) Guidelines for Improving Flood-resistance for Existing Buildings.National Research Council of Canada. NRC Contract No. 930582. Accessed at: https://nrc-publications.canada.ca/eng/view/ft/?id=c3b54b84-2a25-4e7e-ba3e-01c80378f086

[30] Triodetic Multipoint Foundations, http://multipoint-foundations.com/

INTERVENTION SUMMARY: RAISED INFRASTRUCTURE		
COASTAL RISK	Flooding	
ADAPTIVE RESPONSE	Accommodate	
GREY TO GREEN SPECTRUM (GREY, GREEN – SEDIMENT BASED, GREEN – VEGETATION)	Grey	
COST ($ LOW, $$ MEDIUM, $$$ HIGH)	$$$	
MAXIMUM WAVE EXPOSURE	Protected	
SEDIMENT SUPPLY REQUIRED?	No	
IDEAL POSITION IN COASTAL PROFILE (NEARSHORE, FORESHORE, BACKSHORE)	Backshore	
PROTECTION (GOOD, NEUTRAL, NEGATIVE/CAUSING EROSION OR FLOODING)	*Coast (above high tide)*	Neutral
	Natural tidal zone	Neutral
	Flood defence	Good
IMPACTS (POSITIVE, NEUTRAL, NEGATIVE)	*Downdrift beach*	Neutral
	Aesthetics	Neutral
	Swimming safety	Neutral
SUSTAINABILITY & PRESERVATION (ENHANCES SUSTAINABILITY, NEUTRAL, NOT SUSTAINABLE)	*Coastal morphology*	Neutral
	Habitat/ biodiversity	Neutral
OPPORTUNITIES:	• Suitable for most coastal types. • Can be an effective means of reducing the impact of flooding for individual buildings. • Can be required through land use by-laws for buildings in at-risk areas. • More affordable than the construction of elaborate flood protection works such as seawalls and dyke systems.	
CONSTRAINTS:	• Access to the structure is limited during flood events. • Building code regulations may restrict available options (to be determined by a professional engineer). • Costs of building raised infrastructure increase with the required height.	

3.23 Floating building/amphibious foundation

A number of techniques for floating buildings have evolved over the last few decades. Some of the most stable are based on a reinforced concrete exterior shell with a core of buoyant expanded-polystyrene. Large floating foundations, such as pontoons, docks, or floats, are often built in one piece close to the construction site where launching and transportation of the foundation is practical. Foundations can also be built in components off-site and assembled as a single piece close to the construction location. Structures are built upon this foundation once it is in place. Floating sections such as walkways are joined with connections allowing some mobility between them.

Amphibious foundations are a relatively new innovation. The building rests on the ground with a fixed foundation but rises and allows water to flow underneath during floods. A wet dock under the building collects water and lifts the building during an extreme flood. Fixed vertical posts hold the building in place and prevent it from floating away. Estimates from various sources suggest that an amphibious home's construction costs may be 20–30% more than a standard fixed foundation home.

Figure 3.27 Home on an amphibious foundation in Holland (Dura Vermeer)

Intervention Summary: Floating Building/Amphibious Foundation		
Coastal Risk	Flooding	
Adaptive response	Accommodate	
Grey to Green Spectrum (Grey, Green – Sediment Based, Green – Vegetation)	Grey	
Cost ($ Low, $$ Medium, $$$ High)	$$$	
Maximum Wave Exposure	Protected	
Sediment supply required?	No	
Ideal position in coastal profile (Nearshore, Foreshore, Backshore)	Backshore	
Protection (Good, Neutral, Negative/Causing Erosion or Flooding)	*Coast (above high tide)*	Neutral
	Natural tidal zone	Neutral
	Flood defence	Good
Impacts (Positive, Neutral, Negative)	*Downdrift beach*	Neutral
	Aesthetics	Neutral
	Swimming safety	Neutral
Sustainability & preservation (enhances sustainability, neutral, not sustainable)	*Coastal morphology*	Neutral
	Habitat/ biodiversity	Neutral
Opportunities:	• Suitable for most coastal types. • Flooding has no negative impact on the homes. • Costs are covered by landowners, rather than being carried by the municipality.	
Constraints:	• Overland access to the structure is limited during floods. • Flooding and erosion may still impact support infrastructure. • Only suitable in low wave energy environments (although some floating bases may be able to withstand medium wave energy environments).	

3.24 Stormwater management – reduce runoff

Stormwater management at the site level includes the following general approaches, each of which are described in more detail on the following pages:

- Reducing runoff by promoting infiltration through low-impact development (LID) and best management practices (BMPs) from planning to construction of a project (described below).
- Increasing the capacity to convey (‘conveyance’) runoff by creating new drainage ditches and sloughs, and/or increasing the conveyance of existing drainage paths along channels and structures such as culverts or bridge openings.
- Storage of water in detainment ponds or lagoons.

Low impact development (LID) is a stormwater management strategy to control increased runoff and stormwater pollution by managing runoff as close to its source as possible. LID uses a range of techniques and technologies to reduce the amount and intensity of stormwater flows into municipal systems. These techniques are referred to as stormwater best management practices (BMPs). BMPs include small-scale structural practices that mimic natural or pre development water flow. Natural processes include infiltration, evapotranspiration, harvesting, filtration and detention of stormwater. The goal of LID for new developments and reclamation is to improve the required infrastructure (e.g., storm drains) without adding large costs to the development. Initial costs are offset by the decrease in peak runoff flows, flooding, associated damages, and larger infrastructure requirements downstream. New development options that must be examined for the site by a municipal/water resources engineer include:

- grass swales
- permeable pavement
- perforated pipe systems
- wet ponds
- dry detention ponds
- constructed wetlands
- vegetative filter strips

Figure 3.28 Grass swale in Yarmouth, NS (Alexander Wilson, CBCL Limited)

Intervention Summary: Stormwater Management (Reduce Runoff)		
Coastal Risk	Flooding	
Adaptive response	Accommodate	
Grey to Green Spectrum (Grey, Green – Sediment Based, Green – Vegetation)	Green-grey hybrid	
Cost ($ Low, $$ Medium, $$$ High)	$	
Maximum Wave Exposure	N/A	
Sediment supply required?	No	
Ideal position in coastal profile (Nearshore, Foreshore, Backshore)	Backshore	
Protection (Good, Neutral, Negative/Causing Erosion or Flooding)	*Coast (above high tide)*	Neutral
	Natural tidal zone	Neutral
	Flood defence	Good
Impacts (Positive, Neutral, Negative)	*Downdrift beach*	Neutral
	Aesthetics	Neutral
	Swimming safety	Neutral
Sustainability & preservation (enhances sustainability, neutral, not sustainable)	*Coastal morphology*	Neutral
	Habitat/ biodiversity	Neutral
Opportunities:	• Reduces the volume and intensity of stormwater flow during heavy rain. • Decreases risks of flooding and pollution. • Improves municipal stormwater systems while minimizing maintenance requirements. • Cost effective at the planning stage. • Captures water run-off contaminants. • Protects or increases habitats.	
Constraints:	• Provides limited protection from extreme flooding when the ground is already saturated. • Must be located above sea level. • May require a large area of land.	

3.25 Stormwater management – increase conveyance (drainage ditch)

Drainage ditches and sloughs are made up of a network of open trenches often connected by culverts. The trenches are below the surrounding land by a few feet and drain into the ocean or lagoons and detainment ponds (ponds made to store excess stormwater). In the case of flooding, water will spill into the ditches rather than travel further inland. Proper drainage increases how quickly the land can recover from being flooded, reduces cleanup time, and prevents standing water from settling on the land. Increasing the ability to convey stormwater (‘conveyance’) can also be achieved by modifying existing drainage paths along channels and structures through culverts or bridge openings.

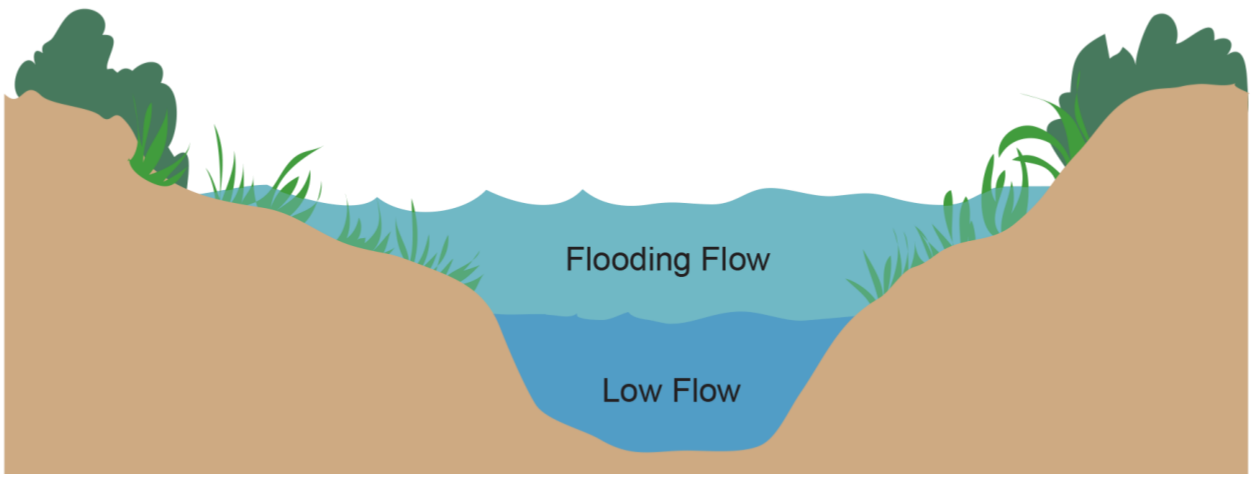

Figure 3.29 Example of two-stage drainage ditch with extra conveyance for flood events (after Vincent Leys, CBCL Limited)

INTERVENTION SUMMARY: STORMWATER MANAGEMENT – INCREASE CONVEYANCE (DRAINAGE DITCH)		
COASTAL RISK	Flooding	
ADAPTIVE RESPONSE	Accommodate	
GREY TO GREEN SPECTRUM (GREY, GREEN – SEDIMENT BASED, GREEN – VEGETATION)	Grey	
COST ($ LOW, $$ MEDIUM, $$$ HIGH)	$	
MAXIMUM WAVE EXPOSURE	N/A	
SEDIMENT SUPPLY REQUIRED?	No	
IDEAL POSITION IN COASTAL PROFILE (NEARSHORE, FORESHORE, BACKSHORE)	Backshore	
PROTECTION (GOOD, NEUTRAL, NEGATIVE/CAUSING EROSION OR FLOODING)	*Coast (above high tide)*	Neutral
	Natural tidal zone	Neutral
	Flood defence	Good
IMPACTS (POSITIVE, NEUTRAL, NEGATIVE)	*Downdrift beach*	Neutral
	Aesthetics	Neutral
	Swimming safety	Neutral
SUSTAINABILITY & PRESERVATION (ENHANCES SUSTAINABILITY, NEUTRAL, NOT SUSTAINABLE)	*Coastal morphology*	Neutral
	Habitat/ biodiversity	Neutral
OPPORTUNITIES:	• Provides drainage areas for flooding. • Increases habitat. • Relatively cost-effective. • Can usually be implemented without the permission of higher levels of government. • For buildings in a flood zone, costs are incurred by developers and landowners, rather than being carried by the municipality.	
CONSTRAINTS:	• Does not provide protection from extreme flooding, only increases recovery after the event. • Buildings may still be at risk from flood events. • Increasing drainage upstream in a watershed system may increase flooding risks downstream.	

3.26 Stormwater management – increase storage (detainment pond)

Lagoons and detainment ponds are usually built with sloughs and drainage ditches to provide a network of flood management for inland flooding. In coastal areas detainment ponds can be used along with other protection measures such as dykes and marshland restoration. These constructed water bodies provide a place for water to collect during extreme events. Water is slowly drained or pumped from the area after flooding has stopped. Detainment ponds also act as settling ponds for water contaminants.

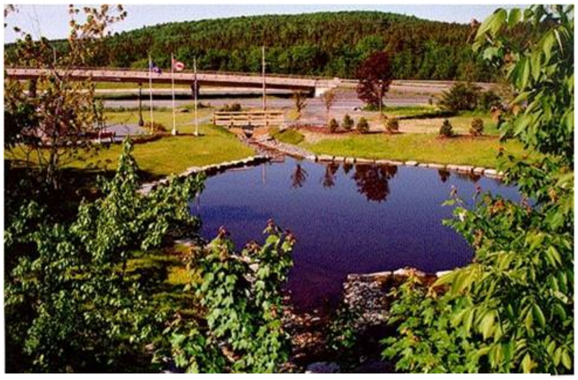

Figure 3.30 Cenotaph Pond, Sackville NS (Mike DeLay, CBCL Limited)

Intervention Summary: Stormwater Management – Increase Storage (detainment Pond)		
Coastal Risk	Flooding	
Adaptive Response	Accommodate	
Grey to Green Spectrum (Grey, Green – Sediment Based, Green – Vegetation)	Grey	
Cost ($ Low, $$ Medium, $$$ High)	$	
Maximum Wave Exposure	N/A	
Sediment supply required?	No	
Ideal position in coastal profile (Nearshore, Foreshore, Backshore)	Backshore	
Protection (Good, Neutral, Negative/Causing Erosion or Flooding)	*Coast (above high tide)*	Neutral
	Natural tidal zone	Neutral
	Flood defence	Good
Impacts (Positive, Neutral, Negative)	*Downdrift beach*	Neutral
	Aesthetics	Neutral
	Swimming safety	Neutral
Sustainability & preservation (enhances sustainability, neutral, not sustainable)	*Coastal morphology*	Neutral
	Habitat/ biodiversity	Enhances sustainability
Opportunities:	• Useful as part of a larger network of inland flood protection. • Reduces the extent and intensity of flooding downstream by capturing and releasing water back into the natural system slowly. • If designed properly can be a recreational and environmental asset to a community. • Captures water contaminants. • Increases habitat.	
Constraints:	• Must be located above sea level. • Volume of flood water that the ponds can deal with is restricted. • Requires a large area of land.	

3.27 Stormwater management – rain garden/constructed wetland

The purpose of a rain garden is to act as a defence to flooding due to heavy rainfall in urban areas with surrounding impermeable surfaces where water cannot be absorbed. Multiple rain gardens are typically planted in different locations to collectively absorb more rainwater. Rain gardens function by absorbing more rain than a standard lawn and releasing it into the soil at a slower rate. Gutters and downspouts can be installed on surrounding buildings to direct the rain from the buildings into the rain garden. Rain gardens should be planted a minimum of 3 metres from a building to avoid damaging the foundation, on a surface with a maximum slope of 12%, and be composed of deep-rooted native plants.[31] If the rain garden is planted on a slope, a berm on the lower side of the garden helps retain the rainwater.

Constructed wetlands are larger than rain gardens and are constructed in a depression in the landscape. Constructed wetlands absorb water running off paved surfaces and filter pollutants from the stormwater runoff. Successful rain gardens and constructed wetlands depend on plants which thrive with large amounts of freshwater.

Figure 3.31 Raingarden in Sackville, NB[19] (Amanda Marlin, EOS Eco-Energy)

[31] Marlin, A. (2013). Sackville Rain Gardens: A Sustainable StormWater Management Pilot Project. Regional Centre of Expertise for Sustainable Development – Tantramar.

Intervention Summary: Stormwater Management – Rain Garden/Constructed Wetland		
Coastal Risk	Flooding	
Adaptive Response	Accommodate	
Grey to Green Spectrum (Grey, Green – Sediment Based, Green – Vegetation)	Grey	
Cost ($ Low, $$ Medium, $$$ High)	$	
Maximum Wave Exposure	N/A	
Sediment Supply Required?	No	
Ideal Position in Coastal Profile (Nearshore, Foreshore, Backshore)	Backshore	
Protection (Good, Neutral, Negative/Causing Erosion or Flooding)	*Coast (above high tide)*	Neutral
	Natural tidal zone	Neutral
	Flood defence	Good
Impacts (Positive, Neutral, Negative)	*Downdrift beach*	Neutral
	Aesthetics	Positive
	Swimming safety	Neutral
Sustainability & Preservation (Enhances Sustainability, Neutral, Not Sustainable)	*Coastal morphology*	Neutral
	Habitat/ biodiversity	Enhances sustainability
Opportunities:	• Reduces runoff from rainfall. • Reduces the volume of water going into storm drains during storms. • Relatively cost-effective. • Easy to build. • Provides habitat and biodiversity.	
Constraints:	• Relatively small-scale solution. • Multiple rain gardens are recommended.	

3.28 Managed retreat/relocate infrastructure

The decision to relocate a coastal road, building, or other type of infrastructure must be based on a cost-benefit analysis that includes socio-economic aspects and accounts for the value of services provided by the infrastructure. For example, the decision to relocate a road must consider the value of the services provided by the road and their relative relocation costs. Additional costs may include moving homes, buildings, or other infrastructure, or rebuilding new infrastructure in the new location.

Intervention Summary: Managed Retreat		
Coastal Risk	Erosion and flooding	
Adaptive response	Retreat	
Grey to Green Spectrum (Grey, Green – Sediment Based, Green – Vegetation)	N/A	
Cost ($ Low, $$ Medium, $$$ High)	$$$	
Maximum Wave Exposure	Exposed	
Sediment supply required?	No	
Ideal position in coastal profile (Nearshore, Foreshore, Backshore)	Backshore	
Protection (Good, Neutral, Negative/Causing Erosion or Flooding)	*Coast (above high tide)*	Neutral
	Natural tidal zone	Good
	Flood defence	Good
Impacts (Positive, Neutral, Negative)	*Downdrift beach*	Neutral
	Aesthetics	Neutral
	Swimming safety	Neutral
Sustainability & preservation (enhances sustainability, neutral, not sustainable)	*Coastal morphology*	Neutral
	Habitat/ biodiversity	Enhances sustainability
Opportunities:	• Long-term sustainability for at-risk areas. • Lower maintenance costs. • Opportunity to build more resilient and upgraded infrastructure.	
Constraints:	• Capital costs for relocation are high. • Potential land ownership and socio-economic challenges. • Potential community perceptions of “abandonment”.	

Chapter 4: Case Studies

This chapter presents a selection of case studies that illustrate the application of the various interventions described in Chapter 3. Examples were collected from the work experience of the authors, supplemented by literature sources. They stand as general illustrations of intervention options in the context of a small to medium-sized coastal community. Where possible, we gave priority to examples showing new or innovative designs and taking into consideration the specific characteristics of the site and material availability. A list of supplementary material with more extensive descriptions and other examples is provided in Chapter 6: Further Reading.

4.1 Bank stabilization and living shoreline project at Shelburne, NS

Figure 3.32 Before (March 2020) and after (August 2020) implementation of living shoreline practices to stabilize the bank (Coastal Action, CBWES)

Intervention	Living shoreline
Location	Shelburne, NS
Year:	2020
Wave climate:	Low/Medium
Coastal characteristics:	The Shelburne Harbour is a long inlet with two arms extending approximately 15 km from the open ocean. McNutts Island is located at the harbour entrance and serves as protection to the inner harbour and shore from high energy waves.
Project description:	The town of Shelburne is located at the head of the Shelbourne Harbour on Nova Scotia's southwest coast. Although most of the town is underlain by granite bedrock, the overlying till was exposed at the shoreline and is eroding. Much of the Town's shoreline is armoured with engineered structures/coastal interventions, but the land behind some interventions was susceptible to scouring caused by overland runoff and over topping. To absorb and slow overland flow while also providing protection from wave erosion, a living shoreline was installed. The living shoreline incorporated logs, haybales, and native vegetation. As a result, approximately 93 m^2 of self-sustaining shoreline was restored and is predicted to absorb 27.3 m^3 of stormwater per year, ultimately reducing overland flow, erosion, scouring, and flooding impacts.[32]

[32] Town of Shelburne Bank Stabilization and Living Shoreline Project, School of Planning Dalhousie University, Halifax NS, MRfM+Shelburne_Case_Study_Final_Dec05_2021_updated.pdf (squarespace.com)

4.2 Fundy National Park highway and beach stabilization

Figure 3.33 Breakwaters at Fundy National Park (Vincent Leys, CBCL Limited)

Intervention	Revetment, beach nourishment, vegetation, salt marsh stabilization
Location	Fundy National Park, New Brunswick
Year:	2018
Wave climate:	High
Coastal characteristics	High tides, heavy wind and wave activity
Project description:	Highway 114 is a main transportation route in southeast New Brunswick. Approximately 20.6 km of the highway passes through Fundy National Park. At high tide on the Bay of Fundy, which can reach up to 12 m in the area, the shoreline is exposed to waves from the southwest. There is a greater impact when high tide coincides with heavy wave and wind activity. Riprap previously implemented in the area was displaced, structures and beach access boardwalks have been damaged, and debris/rocks have been left on the road from over wash. The objectives of the project were to protect the road and park infrastructure, maintain easy beach access, enhance habitats, and minimize cumulative storm damage mitigation costs. The design included construction of an engineered revetment along the highway embankment, beach nourishment, planting of vegetation, and stabilization of the existing salt-marsh to the south-west of the revetment.

4.3 Carters Beach dune restoration project, Port Mouton, NS

Figure 3.34 Marram grass growth at one of the restoration sites, Carters Beach (left to right – April 2018, September 2019, September 2019) (Coolen in Smith et al., 2019)

Intervention	Dune restoration, vegetation
Location	Port Mouton, NS
Year:	2017
Wave climate:	Medium
Coastal characteristics	Carters Beach coast is characterised by white sand dunes, pockets of rocky islets, and nearby islands. The dunes at Carters beach are the highest of Nova Scotia's Atlantic coast.[33]
Project description:	Climate change is anticipated to cause warmer and wetter conditions in Nova Scotia through more frequent and intense rainfall events, greater storm surge, and sea level rise.[34] These conditions are expected to erode the shoreline at Carters beach and cause the sand dunes to migrate landward and steepen while experiencing vegetation loss.[35] The dunes play a valuable role in the ecosystem and coastal protection, making preservation of high importance. Restoration activities began in 2017 with fencing, educational signage, and marram grass transplants. Monitoring in 2018 indicated the planting was 65-100% successful in terms of plant survival and sediment retention. In 2019, 81 – 100% of the transplanted grasses were able to survive Hurricane Dorian.[36]

[33] Source: Davis, D.S., & Browne, S. (Eds) (1996). Natural History of Nova Scotia Volume 2 Theme Regions. Natural History Museum of Nova Scotia. https://ojs.library.dal.ca/NSM/article/view/3775/3458
[34] ECCC. (2019). Canada's changing climate report. https://changingclimate.ca/site/assets/uploads/sites/2/2019/04/CCCR_FULLREPORT-ENFINAL.pdf
[35] ACASA. (2011). Coastal erosion and climate change. https://www.csrpa.ca/wpcontent/uploads/2017/11/coastal_erosion_and_climate_change_0.pdf
[36] Carters Beach Dune Restoration Project, School of Planning, Dalhousie University, 2021 MRfM_Carters_Beach_Case_Study_Final_Dec05_21_Updated.pdf (squarespace.com)

4.4 Dune restoration Crowbush Golf Course, PEI

Figure 3.35 Marram grass established on re-built dune (over buried revetment) at Crowbush Golf Course.

Intervention	Dune restoration, vegetation, buried revetment
Location	Lakeside, Prince Edward Island
Year:	2006
Wave climate:	High
Coastal characteristics	Sand dunes and sandstone cliffs
Project description:	Widespread erosion and disappearing dunes have been occurring at Brackley Beach for over 20 years. In 2001 in particular, storms washed away dunes that protected features of the Crowbush golf course. The golf course is highly ranked in North America and serves as a valuable component of the tourism industry. The dunes were rebuilt using a buried revetment structure consisting of an armour stone core. Marram grass was planted to stabilize the dune and enhance natural characteristics. Although the dune can be washed away in storms again, the underlying armour stone will provide further protection to the golf course and other inland infrastructure. The dunes continue to be maintained and revegetated.

4.5 Armour stone revetment along Cow Bay Causeway, Cole Harbour, NS

Figure 3.36 Cow Bay Causeway experiencing a storm in 2010.

Intervention	Armour stone revetment
Location	Cow Bay Causeway, Cole Harbour, NS
Year:	2013
Wave climate:	High
Coastal characteristics	Cobble barrier beach
Project description:	The Cow Bay Causeway is built over a beach of cobble and boulder. There was an improperly sized breakwater and armouring in place that was frequently overtopped by waves, causing extensive damage to the causeway requiring regular repair. The Halifax Regional Municipality commissioned a study to analyze future tidal and storm-surge conditions and the anticipated performance of the breakwater. As a result, the armour stone revetment was entirely rebuilt to accommodate higher sea levels and storm surge conditions. The new revetment has been successful in mitigating the effects of heavy storms and wave action.

4.6 Inter-tidal reefs, Souris PEI

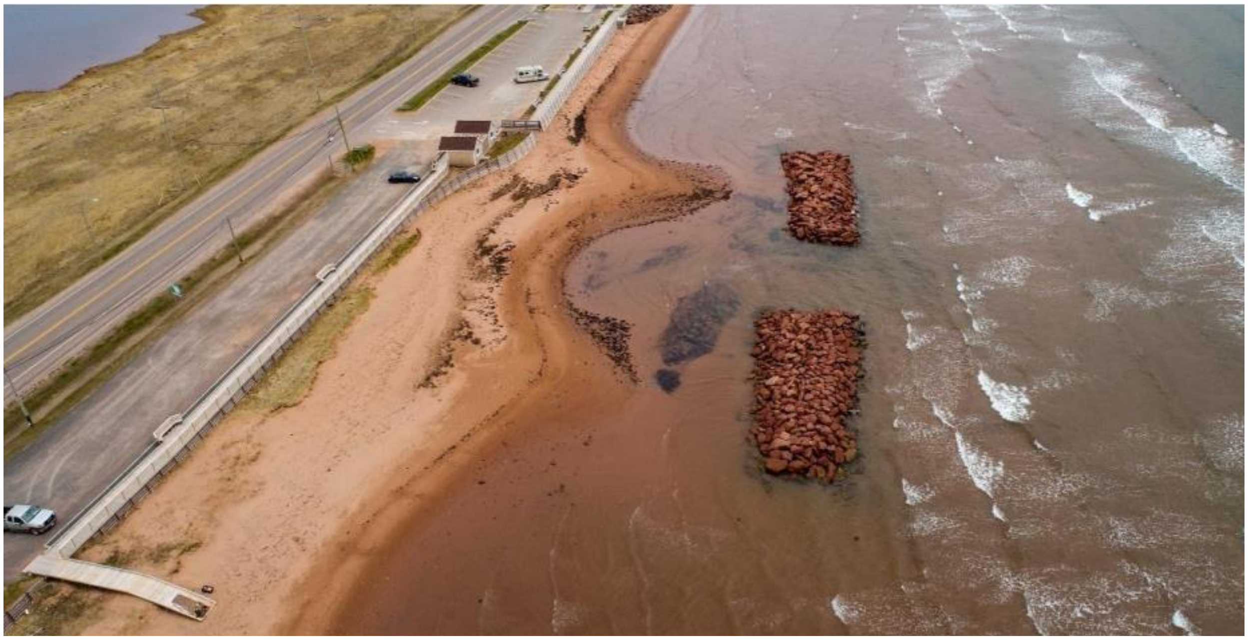

Figure 3.37 Detached breakwaters or intertidal reefs being used for beach stabilization and protection in Souris, PEI.

Intervention	Seawall, dune restoration, shoreline stabilization, inter-tidal reefs
Location	Souris, PEI
Year:	2018
Wave climate:	Medium
Coastal characteristics	Small dunes, sandstone bluffs
Project description:	Damage to the PEI portion of the Trans-Canada Highway was occurring as a result of storms and erosional hazards, which are expected to worsen with climate change. The Highway serves as a vital link to the Town of Souris and the Inter-Provincial Ferry to the Magdalen Islands. To protect the highway, the following measures were implemented: • A timber seawall with set-back allowing for beach restoration. • Dune restoration and shoreline stabilization, including two intertidal reefs. The reefs dampen the effects of storm waves on the beach and highway infrastructure, allowing sand to be deposited along the shore. As a result, the beach width increased, and infrastructure was protected. Subsequent monitoring indicated that growth and vegetation of the landward dunes occurred due to an increased dry beach area.[37]

[37] Davies, M.H. and B.F. Thompson. 2019. “Protecting the Trans-Canada Highway at Souris with Inter-tidal Reefs.” Paper prepared for Transport Association of Canada Joint Conference, Halifax, NS. Accessed at: https://www.tac-atc.ca/sites/default/files/conf_papers/daviesm_-_protecting_the_trans-canada_highway_ at_souris_with_inter-tidal_reefs_-_v1.pdf

4.7 Stratford Point salt marsh restoration

Figure 3.38 Concrete reef ball installation along Stratford Point (National Audubon Society Inc., 2020)

Intervention	Artificial reef
Location	Long Island Sound, Connecticut
Year:	2014
Wave climate:	Medium to High
Coastal characteristics	Previously a beach with sand dunes that were removed anthropogenically.
Project description:	For 60 years, the north cove of Stratford Point was a shooting range. The foreshore was polluted with lead shot. Sand dunes were removed to improve views and oyster reefs were mined for road building material. DuPont Corporation, Sacred Heart University, and the Connecticut Audubon Society partnered to clean up and install the artificial reef. This project was carried out through a private, institutional, and non-profit partnership. Sixty-five reef balls were installed on the foreshore of a 3.5-acre intertidal area in the north cove of Stratford Point, Connecticut. The balls help to reduce erosion and restore the reefs and salt marshes in the area. Four sizes of reef balls were installed in four rows of ten. A 20 m long biodegradable sock filled with bivalve shells (types of mollusks) was snaked through the middle two rows of reef balls to add stability and enhance the breeding environment for oysters. Since installation in 2014, the marshes have filled in density and grown in height. Just two years after installation, sand deposits rose 30 cm in some areas around the reef. The salt marsh grasses doubled in size.[38] There are also oysters and blue mussels on the bottoms of the reef.[39] In 2020, the project received the Best Restored Shore Award from the American Shore & Beach Preservation Association.

[38] 2022 National Audubon Society, Inc., 225 Varick Street, 7th Floor, New York, New York 10014, USA. https://ct.audubon.org/news/stratford-point-receives-best-restored-shore-award
[39] Westfair Business Publications, 2021. https://westfaironline.com/132114/shus-shoreline-project-expands-preservation-of-stratford-point-marshland/

4.8 Dredging and beach nourishment, North Topsail Beach, North Carolina

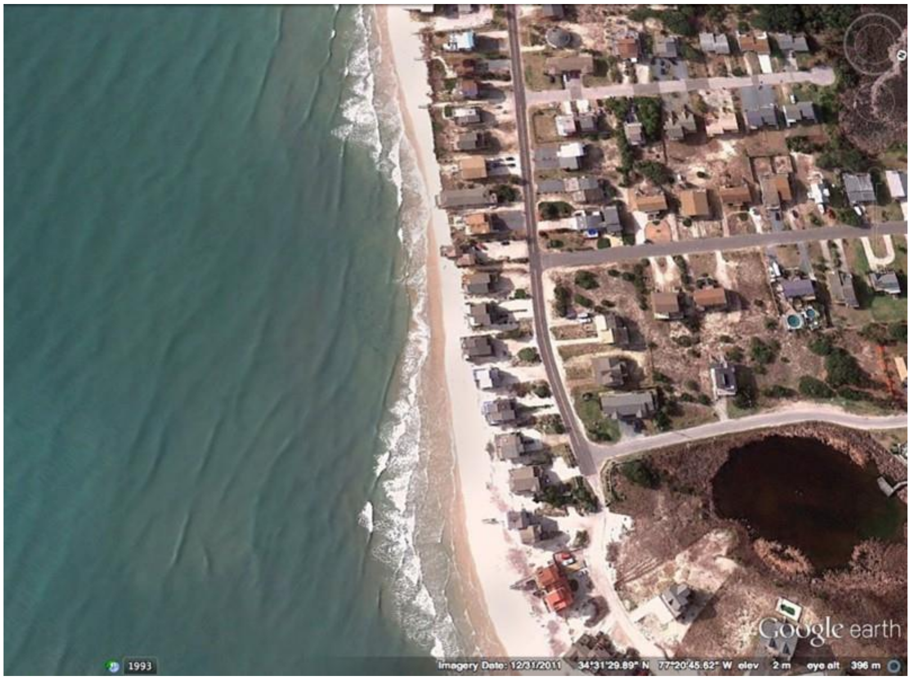

Figure 3.39 After beach nourishment at Topsail Beach, NC (Google Earth)

Intervention	Dredging, beach nourishment
Location	North Topsail Beach, North Carolina
Year:	2013
Wave climate:	High
Coastal characteristics	Developed beaches
Project description:	The town of Topsail Beach, North Carolina, is on a long narrow strip of land (spit) of primarily sand with water on both sides of the town. The beach front is mostly developed with a mix of recreational areas and some nature reserves. The New River Inlet Channel Realignment and Beach Restoration Project, completed January 2013, was the first phase of a five-phase plan to restore 18 kilometers of shoreline. In Phase One, 430,000 cubic metres of sand was dredged from the channel. This increased its depth to 5 metres and its width to 152 metres. The sand removed from the channel was used to rebuild the beach on the north end of Topsail Island.[40] Benefits Beyond a Nice Beach – The location has been heavily impacted by hurricanes which have historically caused heavy erosion. By complying with federal requirements for an engineered beach, the town will now be eligible for federal beach restoration funds for damage caused by major storm events in the future.[41]

[40] JDNews. (2014). NTB named one of America's best-restored beaches. [image]. Published: Monday, May 19, 2014 at 11:08 AM, JDNews.com, Jacksonville, NC
[41] Faulkner, C. (2013). Town of North Topsail Beach Press Release – New River Inlet Channel Realignment Project - 2/7/2013

4.9 Eco-friendly seawall in North Turramurra, NSW, Australia

Figure 3.40 Bobbin Head seawall (D.Wiecek, Office of Environment and Heritage)

Intervention	Seawall
Location	New South Wales, Australia
Year:	2012
Wave climate:	Low
Project description:	Bobbin Head, in Apple Tree Bay is a sheltered area within the Ku-ring-gai Chase National Park North of Sydney, Australia. This seawall highlights a number of design principles that allow for more natural habitat. Design principles include gentle slopes and a varied surface.[42] The wall is constructed with rocks from nearby sources. While seawalls act as buffers against shoreline erosion, their construction means that intertidal vegetation is removed or will eventually die off.[43] The natural ability of sea plants to encourage sediment deposition and restrict erosion is then lost. When a vertical hard structure is built, erosion often increases at the toe or ends of the structure. In contrast, this seawall features uneven surfaces at a gentle slope to encourage sediment deposition and plant growth within pools.[44,45]

[42] DeWeerdt, S. (2012). How to Build a Living Seawall. Conservation Magazine: March 9, 2012. Retrieved from http://conservationmagazine.org/2012/03/how-to-build-a-living-seawall/

[43] Browne, M.A., & Chapman, M.G. (2014). Mitigating against the loss of species by adding artificial intertidal pools to existing seawalls. Marine Ecology Progress Series, 497, 119-129

[44] Wiecek, D. (2009). Environmentally Friendly Seawalls a Guide to Improving the Environmental Value of Seawalls and Seawall-lined Foreshores in Estuaries. Retrieved from http://www.hornsby.nsw.gov.au/__data/assets/pdf_file/0017/41291/Environmentally-Friendly-Seawalls.pdf

[45] Wiecek, D. (2008). Management Guidelines for Improving the Environmental Value of Seawalls and Seawall-Lined Estuary Foreshores. Coastal Conference Proceedings: November 2008. Retrieved from http://www.coastalconference.com/2008/papers2008/Wiecek,%20Danny%206C.pdf

4.10 Basin Head Provincial Park groynes

Figure 3.41 T-Head groyne at Basin Head Provincial Park, PEI (Vincent Leys, CBCL Limited)

Intervention	Groynes
Location	Basin Head Provincial Beach Park, PEI
Year:	2022
Wave climate:	High outside and low inside the estuary
Coastal characteristics	Strong tidal currents, high rates of erosion and sediment transport inside the channel.
Project description:	Basin Head is a very popular day use Provincial Beach Park in eastern Prince Edward Island. It features an estuary connected to the Gulf of St Lawrence through a tidal inlet running between parallel piers (the Run). The Run is a popular spot for swimming, and until recently had remained deep enough for bathers to jump from the wharves and bridge. In recent years sedimentation in the run has accelerated, requiring frequent dredging. In the summer of 2020, a ban on jumping off the structures was required for safety, after rapid infill following the latest dredging. There are many sediment sources to the system. Coastal sources have increased in the last decade due to loss of ice cover, and various storm events overtopping the dunes. The prevailing source in the last decade appeared to be erosion of the inner east bank. Groynes were designed to stabilize the bank, deflect the tidal currents away back to the centre of the channel and hold a pocket beach. The groynes were built in 2022 with aesthetically fitting local island sandstone, along with south dune reconstruction, and successfully realigned the channel away from the bank while providing a sand beach for swimmers to safely exit the Run. Dredging was not required in the year of installation. The project returned the tidal channel to a stable regime, providing natural climate change resiliency to a key tourism destination in PEI.

4.11 North Rustico (PEI) wastewater treatment plant (WWTP) relocation

Figure 3.42 Flooding in North Rustico, PEI, December, 2010 (Don Jardine, University of Prince Edward Island)

Location	North Rustico, PEI, Canada
Year:	2014
Wave climate:	Medium
Coastal characteristics	Small dunes, sandstone bluffs
Project description:	North Rustico is a coastal community on Prince Edward Island's North Shore. The community was flooded in December 2010 when a major storm surge hit at high tide. The flooding was the most extensive ever recorded in the community. The flood impacted the wastewater treatment plant, which leaked pollution into the harbour as a result of the damage. The community updated its flood maps and identified infrastructure at risk of flooding and requiring relocation. The relocation process for the wastewater treatment plant started in 2011. The site selected for a new treatment plant was a community-owned former landfill site, located on high ground one kilometre away from the town. Construction started in 2013 and was completed in 2014. The old plant was removed from the coastal location and a new pumping station was built in its place, but one metre higher than the former structure. The new pumping station has an on-site generator to minimize future flood impacts. All three levels of government helped fund the project. The Town was awarded the Excellence in Water Stewardship Award by the Council of the Federation for this successful relocation project.

4.12 Wide green dyke around the Ems-Dollard Estuary, Netherlands

Figure 3.43 Aerial View from the Ems-Dollard dyke and Clay Pits (Regional Water Authority Hunze en Aa's)[46]

Intervention	Dykes
Location	Ems-Dollard Estuary, North Sea, The Netherlands
Year:	2018
Wave climate:	Medium
Project description:	The area around the Ems River Estuary in the Netherlands was reclaimed from the sea centuries ago, but with sea level rise and erosion the dyke system had to be upgraded. New broad green dykes were created as part of the national government's Wadden Area Delta Programme in partnership with Rijkswaterstaat's Corporate Innovation Programme, the Rich Wadden Sea Programme, and the Rural Area Department. A recent pilot project aims to investigate the potential for the dykes to be reinforced with excess sediment from the Dollard. The so-called "Wide Green dyke'' pilot is a wide and gradually sloping dyke that merges smoothly into the salt marsh without additional asphalt protection at the seaward side of the dyke. Most importantly, the dyke will be reinforced over time with the excess sediment from the Dollard. Wide Green dykes – The cost per kilometre of a wide green dyke is lower than hard dykes because asphalt, concrete, and stone revetment is not needed. The larger base width of the dyke, in combination with the marsh, makes it less susceptible to seepage and reduces the need for piping, factors which can make dykes unstable.[47]

[46] Marijnissen, R., Esselink, P., Kok, M., Kroeze, C., van Loon-Steensma, J.M., 2020. How natural processes contribute to flood protection – A sustainable adaptation scheme for a wide green dyke . Science of The Total Environment 739, 139698. https://doi.org/10.1016/j.scitotenv.2020.139698
[47] Marijnissen, R., Kok, M., Kroeze, C., & van Loon-Steensma, J. (2020). The Sensitivity of a Dyke-Marsh System to Sea-Level Rise—A Model-Based Exploration. Journal of Marine Science and Engineering, 8(1), 42. https://doi.org/10.3390/jmse8010042

4.13 La Planche River aboiteau, Bay of Fundy, Amherst NS

Figure 3.44 La Planche River Aboiteau near completion, August 2015 (Suvir Pursnani, CBCL Limited)

Location	Amherst, NS, Canada
Year:	2017
Wave climate:	Low
Coastal characteristics	Extreme tidal range
Project description:	An aboiteau is a one-way hydraulic gate through a coastal dyke. It protects agricultural lands by blocking the high tides and letting the river discharge through the dyke on the low tide. In the context of sea level rise and potentially larger flood events, the old aboiteau on the La Planche River, Amherst, NS, needed to be replaced. The engineering design of a new structure focused on improving resilience to climate change and sea level rise while mitigating sedimentation and flooding impacts. First, the new aboiteau was relocated downstream of the river to decrease the length of dykes requiring maintenance. Second, the structure was designed to a higher elevation to account for sea level rise. Extreme water levels were determined based on storm surge, tidal elevations and sea level rise projections. Based on costs vs. benefits, the design crest elevation was selected to accommodate the expected 1-in-100-year storm surge level in 2055 (also close to the 1-in-10 year storm in 2085). An extra allowance was added to accommodate post-construction settlement. Additional flexibility was also built-in. In the future it will be possible to raise the crest if necessary, by a combination of steepening a section of one slope, and/or optionally narrowing the crest.

4.14 State of Maine towns, mandatory structure flood proofing

Figure 3.45 Example of a removable floodwall/gate in Maine[48]

Figure 3.46 Proposed expanded 100-year flood zones for town of Old Orchard Beach[49]

Location	Maine, USA
Wave climate:	Medium to High
Coastal characteristics	Extreme tidal conditions
Project description:	The towns of York and Old Orchard Beach have coastlines characterized by sandy beaches of up to a mile long that terminate in headlands. The historic villages, particularly York Beach and Old Orchard Beach, are located in vulnerable locations. Significant flooding occurred during the Patriot's Day storm in 2007 and the Mother's Day storm in 2008. About ten properties are flooded repeatedly in York Beach alone. The state of Maine requires a minimum of one foot freeboard above expected flood levels. Freeboard is defined in the town of Old Orchard Beach floodplain management ordinance (by-law)[50] as "a factor of safety usually expressed in feet above a flood level for purposes of floodplain management. Freeboard tends to compensate for many unknown factors, such as wave action, bridge openings, and the hydrological effect of urbanization of the watershed that could contribute to flood heights greater than the height calculated for a

[48] Flood Control America. (n.d.). Example of removable floodwall. [image]. Retrieved from http://floodcontrolam.com/flood-wall-applications/flood-proofing/

[49] Woodard & Curran, Esri. (2015). FEMA Floodplains in Old Orchard Beach, Maine. [image] Retrieved from https://eis.woodardcurran.com/Html5Viewer/Index3.html?configBase=https://eis.woodardcurran.com/Geocortex/Essentials/REST/sites/OOB/viewers/viewer/virtualdirectory/Resources/Config/Default

[50] Town of Old Orchard Beach. (2006). Code of Ordinances Town of Old Orchard Beach, Maine Chapter 70 Floods Article II Flood Plain Ordinance Management Section 70-32 Development Standards Retrieved December 22, 2015 from:https://www.municode.com/library/me/old_orcharc_beach/codes/code_of_ordinances?nodeId=PTIICOOR_CH70FLARTIIFLMAOR

	selected size flood and floodway conditions.[51] In practical terms for structures this means the elevation of the first floor is above predicted flood levels. Structures are built to comply with the freeboard requirements. The town of Old Orchard Beach has adopted the one-foot minimum freeboard for structures in designated flood areas. The town of York goes further and requires two feet of freeboard.[52] The ordinance applies to all new construction or substantial improvements to any residence. Residential and non-residential structures must have two feet of freeboard or the structure must be flood proofed to two feet above the 100-year flood elevation. Permits are required for non-residential structures to ensure that they meet certain flood proofing standards. Property owners may also apply dry flood proofing for added protection. One example of dry flood proofing is temporary barriers that can be installed in advance of a flood and removed after the flood event is over. FEMA has recently updated flood zone mapping and towns will need to respond with updated regulations. The process and results have been controversial because the mapped flood zones are expanding in many cases; more properties may end up in the expanded flood which has implications for property values and insurance.[53] It also means an expansion of the area where the flood management ordinance will apply.

[51] Town of Old Orchard Beach. (2006). Code of Ordinances Town of Old Orchard Beach, Maine Chapter 70 Floods Article II Flood Plain Ordinance Management Section 70-27 Definitions. Retrieved December 22, 2015 from:https://www.municode.com/library/me/old_orcharc_beach/codes/code_of_ordinances?nodeld=PTIICOOR_CH70FLARTIIFLMAOR

[52] Town of York (2012). Flood Management Ordinance. May 18, 2002. Most recently amended May 19, 2012. http://www.yorkmaine.org/LinkClick.aspx?fileticket=M0DrPVGFzRA%3D&tabid=181

[53] Portland Press Herald. (2014). Old Orchard Beach [image]. Retrieved from http://www.pressherald.com/2014/01/20/communities_questioning_the_fairness_of_flood_maps_/

4.15 Wet flood proofing example (international)

Figure 3.47 Example of a flood vent. (Smart Vent Products Inc.)

Figure 3.48 Impact on this flood-proofed housing is minimal despite major impacts on Sea Bright shoreline infrastructure as indicated by the beached sailboat.

Location	Sea Bright, New Jersey
Year:	2012
Wave climate:	Medium to high
Coastal characteristics	Developed, sandy beaches
Project description:	Sea Bright, New Jersey is using multiple structural retrofits to accommodate the community for flooding. Retrofit includes a variety of changes to existing buildings, including raising buildings, and dry and wet flood proofing. In the short-term, the focus in Sea Bright is on helping individual homeowners obtain the funds and permits needed to retrofit their homes. However, Sea Bright is also re-evaluating land development regulations and building codes to ensure that any housing built in the future is able to withstand future 1-in-100-year storm events with minimal damage. A variety of design standards are now being adopted: • Incorporating flood vents (see image above) and breakaway walls (portions that do not provide structural support to the building) in ground level enclosures. • Using reinforced foundations or pilings to improve structural resistance against wind and wave impacts. • Using moisture resistant building materials, such as composite concrete board instead of drywall. • Requiring appropriate design treatments of ground level, flood susceptible areas, to ensure that pedestrian-level streetscapes are not compromised.

4.16 Canoe Pass Floating Village, Ladner, BC

Figure 3.49 Aerial view of Canoe Pass floating village, British Columbia (Google Earth[54])

Intervention	Floating Building
Location	Ladner, BC, Canada Fraser River Estuary, Georgia Straight
Wave Climate	Low
Project description	The community of Canoe Pass is located near the mouth of the south arm of the Fraser River, British Columbia. The surrounding lands consist of salt-marsh and dyked farmlands. The base of each home is unsinkable under any condition. Floating homes are built in one piece on land with the strength to withstand lifting and launching stresses. Foundations are heavy with a low centre of gravity providing a safe, gentle ride. The floating foundations are designed to last longer than the structures built on top. The development was the first titled, a 'floating village' in Canada. A water lot lease is required and registered and renewed at the Land Title Office every 20 years (1995–2015). The water lease is continuously renewable because the foreshore is owned by the community. There is a high standard of maintenance and upkeep of the development. Unexpected events will be covered by a perpetually accumulating contingency reserve fund.

[54] Google Earth. (2014). *Image of Canoe Pass Floating Village, British Columbia*. [image]. Retrieved from https://www.google.com/earth/

4.17 Rain garden (bio-filtration zone) in Debert, NS

Figure 3.50 Bio-infiltration zone installation at Debert Industrial Park, Debert, NS (Tracey MacKenzie, 2015)

Intervention	Stormwater management – Rain Garden/constructed Wetland
Location	Debert, NS, Canada
Project description	The municipality of the County of Colchester used the principle of natural filtration and rain gardens for installing a demonstration bio-filtration zone in a local industrial park. Working with experts in landscape construction from Dalhousie University, the Municipality designed this simple strategy to intercept storm water runoff. The area has a sandy sub-soil with good infiltration rates so the basin size is small (not requiring a large area for installation). The bio-filtration zone allows for infiltration within 24 hours of runoff. There is an overflow exit next to the roadside swale.[55] Over time, the vegetation planted along the infiltration zone will fill in the site providing more interception. Runoff from this site eventually makes its way to a nearby stream that flows to the Cobequid Bay (of the Minas Basin), approximately six kilometers from the site.

[55] MacKenzie, T. Personal communication. December 15, 2015.

Chapter 5: Glossary

Bathymetry - Map of the ocean or sea bottom, elaborated from depth measurements.
Downdrift - Downstream position according to the longshore transport.
Foreshore - The part of the shore which lies between the low and high-water marks.
Intertidal area - Area affected by the tide (between high water mark and low water mark).
Littoral transport - Transport of sediment due to hydrodynamic activity (waves and currents) along the coast.
Offshore - Zone at some distance from the coast.
Salt marsh - Coastal ecosystem situated in the tidal zone, inhabited by salt-resistant plants that can sustain to be periodically flooded by tide.
Stormwater - Rainwater that has fallen on the ground.
Storm surge - Combination of wind stress and pressure reduction on the water surface.
Wave climate - Characteristics of waves in a certain location in direction, wave height, averaged out.
Wetland - Ecosystem that is constantly or periodically flooded.

Chapter 6: Further Reading

A number of key documents were used in the development of this guidance document. These reports may also be of interest to communities that want further information on how adaptation strategies are developed in other regions:

- Vouk, I., Pilechi, V., Provan, M., Murphy, E. (2021). Nature-Based Solutions for Coastal and Riverine Flood and Erosion Risk Management. Canadian Standards Association, Toronto, ON. Accessed at: https://www.csagroup.org/article/research/nature-based-solutions-for-coastal-and-riverine-flood-and-erosion-risk-management/

- Bridges, T. S., J. K. King, J. D. Simm, M. W. Beck, G. Collins, Q. Lodder, and R. K. Mohan, eds. 2021. International Guidelines on Natural and Nature-Based Features for Flood Risk Management. Vicksburg, MS: U.S. Army Engineer Research and Development Center. Accessed at: https://ewn.erdc.dren.mil/?page_id=4351

- Coulbourne, W., D.L. Kriebel, R. L. Behm, K.K. McKenna (2021) Guide for design of flood-resistant buildings. National Research Council of Canada. NRC Contract No. 930582. Accessed at: https://nrc-publications.canada.ca/eng/view/ft/?id=96b3275c-b731-4fa6-847e-e2a9a0f080d8

- Behm, R.L., W.L. Coulbourne, D.L. Kriebel, K.K. McKenna (2021) Guidelines for Improving Flood-resistance for Existing Buildings.National Research Council of Canada. NRC Contract No. 930582. Accessed at: https://nrc-publications.canada.ca/eng/view/ft/?id=c3b54b84-2a25-4e7e-ba3e-01c80378f086

- Arlington Group. (2013). Sea Level Rise Adaptation Primer: A toolkit to build adaptive capacity on Canada's South Coasts. Report prepared for British Columbia Ministry of Environment, 150 pp. Accessed at: https://www2.gov.bc.ca/assets/gov/environment/climate-change/adaptation/resources/slr-primer.pdf

Additional references:

- Choy, D. L., Serrao-Neumann, S., Crick, F., Schuch, G., Sanò, M., van Staden, R., ... & Baum, S. (2012). *Adaptation options for human settlements in South East Queensland.* Main report. SEQ CARI, Brisbane.
- Cohn, J. L., Copp Franz, S., Mandel, R. H., Nack, C. C., Brainard, A. S., Eallonardo, A., & Magar, V. (2022). Strategies to work towards long-term sustainability and resiliency of nature-based solutions in coastal environments: A review and case studies. Integrated Environmental Assessment and Management, 18(1), 123-134.
- Countries in Transition (CIT): Coastal Erosion Mitigation Guidelines (The World Association for Waterborne Transport Infrastructure, 2014).
- Eyquem, J. L. (2021). Rising Tides and Shifting Sands: Combining Natural and Grey Infrastructure to Protect Canada's Coastal Communities. Intact Centre on Climate Adaptation, University of Waterloo. https://www.intactcentreclimateadaptation.ca/wp-content/uploads/2021/12/UoW_ICCA_2021_12_Coastal_Protection_Grey_NbS.pdf
- Haasnoot, Marjolijn, et al. "Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world." Global environmental change 23.2 (2013): 485-498.

- Webb, B. M., Dix, B., Douglass, S. L., Asam, S., Cherry, C., & Buhring, B. (2019). Nature-Based Solutions for Coastal Highway Resilience: An Implementation Guide (No. FHWA-HEP-19-042). United States. Federal Highway Administration.
- Zhu, X., Linham, M. M., & Nicholls, R. J. (2010). *Technologies for climate change adaptation. Coastal erosion and flooding.*
- *StormSmart Properties Comparison Chart – Relative Costs of Shoreline Stabilization Options.* (State of Massachusetts, 2014).

Appendix: Summary Tables

This appendix provides summary tables for the various considerations discussed in Chapters 2 and 3. Table A.1 presents the intervention options and typical application by coastal type, or system (See also *Part 1: Guidance for Selecting Adaptation Options*).

Use the following tables for an initial screening of options, see the individual descriptions of the intervention options in Chapter 3.

Table A.2 shows the pairing of intervention measures with site characteristics, specifically wave height and exposure, sediment supply requirements and shore slope.

Table A.3 summarizes the functional characteristics of the tools—where they fit in the shore zone, what type or degree of protection they provide, their impacts, and their long-term sustainability.

Table A.4 details generalized jurisdictional responsibility and the corresponding regulatory authorities for each Atlantic Canadian province while Table A.5 shows typical regulatory requirements for the coastal intervention options.

Lastly, typical cost ranges and maintenance intervals for the coastal intervention options were developed based on feedback from engineers at various levels of government, expertise, and literature sources. The results are summarized in Table A.6.

Table A.1 Intervention options and typical application by coastal type.

Prevailing coastal type and application									
Coastal region		**Estuary**	**Salt marsh**	**Coastal sandy system**	**Cobble beach**	**Cliff/ bluff**	**Rocky shore**	**Built**	**Existing dykelands**
Atlantic Seaboard - NS, NL		√	√	√	√	√	√	√	
Bay of Fundy - NS, NB		√	√		√	√	√	√	√
Gulf of St Lawrence and Northumberland Strait - NS, PEI		√	√	√		√		√	
Intervention P – Protect, A – Accommodate, R – Retreat									
P, A	Living shoreline/wetland	√	√	√	√	√			
P, A	Plant stabilization	√	√	√		√			√
P, A	Dune restoration			√					
P, A	Beach nourishment			√	√	√			
P, A	Perched beach	√	√	√	√	√			
P, A	Artificial reefs	√	√	√	√	√			
P	Revetment	√		√	√	√		√	√
P	Buried revetment			√	√				
P	Rip-rap armouring	√	√			√		√	√
P	Groynes			√					
P	Shore attached breakwaters		√	√	√			√	
P	Detached breakwaters		√	√	√	√		√	
P	Retaining wall	√	√			√		√	
P	Seawall	√	√	√	√	√	√	√	
P	Dyke	√	√	√	√		√		√
P	Scour protection	√	√	√	√	√		√	√
P	Tide barrier/aboiteau	√	√	√	√	√	√	√	√
A	Dredging	√		√					√
P	Dry flood proofing building	√	√	√	√	√	√	√	√
A	Wet flood proofing building	√	√	√	√	√	√	√	√
A	Raised infrastructure	√	√	√	√	√	√	√	√
A	Floating building	√	√	√	√	√	√	√	√
A	Stormwater management	√	√	√	√	√	√	√	√
Managed Retreat	Relocate infrastructure	√	√	√	√	√	√	√	√

Note: Planning tools should be considered at the same time as intervention options, if not first.

Table A.2 Intervention options and typical application by wave exposure.

P – Protect A – Accommodate R – Retreat		**BEST CONDITIONS FOR APPLICATION**				
		Wave climate		**Sediment supply required?**		**Maximum recommended slope (degrees)**
		Maximum wave exposure*	**Wave crests angle with shoreline**	**Initial fill**	**Natural background supply**	
P, A	Living shoreline/wetland	Protected		Yes		10
P, A	Plant stabilization	Protected				60
P, A	Dune restoration	Exposed		Yes	Yes	20
P, A	Beach nourishment	Moderate		Yes	Yes	
P, A	Perched beach	Moderate	Parallel	Yes	Yes	
P, A	Artificial reefs	Moderate				
P	Revetments	Exposed				35
P	Buried revetment	Exposed		Yes	Yes	35
P	Rip-rap armouring	Protected				40
P	Groynes	Exposed	Oblique	Yes		
P	Shore attached breakwaters	Exposed	Oblique			
P	Detached breakwaters	Exposed		Yes		
P	Retaining wall	Protected				90
P	Seawall	Exposed		Yes		90
P	Dyke	Exposed				25
P	Scour protection	Protected				
P	Tide barrier/aboiteau	Moderate				
A	Dredging	Protected			No, avoid	
P	Dry flood proofing building	Protected				
A	Wet flood proofing building	Protected				
A	Raised infrastructure	Protected				
A	Floating building	Protected				
A	Stormwater management	N/A				
Managed Retreat	Relocate infrastructure	Exposed				

Wave exposure	Significant wave height	Distance of open water experiencing a sustained wind
Protected	< 1 m	< 5 km
Moderate	1 to 3 m	5 to 50 km
Exposed	3 m +	50 km +

Table A.3 Functional characteristics of the intervention options

P – Protect A – Accommodate R – Retreat		Typical position in coastal profile (Nearshore Foreshore Backshore)	Protection		Potential Impacts			Potential Long-Term Sustainability	
			Protection of coast above high tide	Beach / tidal zone preservation	Lee side erosion	Aesthetics	Swimming safety	Preservation of coastal dynamics and morphology	Preservation of habitat/ biodiversity
P, A	Living shoreline/wetland	F, B	-	√	-	√	-	√	√
P, A	Plant stabilization	B	√	√	-	√	-	-	√
P, A	Dune restoration	B	√	√	-	√	-	X	√
P, A	Beach nourishment	B	√	√	√	√	-	X	-
P, A	Perched beach	N	-	√	√	√	X	X	-
P, A	Artificial reefs	N	√	√	-	√	X	X	√
P	Revetments	F, B	√	X	X	X	-	X	-
P	Buried revetment	B	√	√	√	√	-	X	-
P	Rip-rap armouring	F, B	√	X	X	X	-	X	-
P	Groynes (groins)	N	√	√	X	X	X	X	-
P	Shore-attached breakwaters	N	√	√	-	X	X	X	-
P	Detached breakwaters	N	√	√	X	X	X	X	-
P	Retaining wall	B	√	-	-	X	-	X	-
P	Seawall	B	√	X	X	X	-	X	-
P	Dyke	F	-	-	-	X	-	X	X
P	Scour protection	F	√	X	X	X	-	X	-
P	Tide barrier/aboiteau	F	√	-	-	-	-	X	X
A	Dredging	F	-	X	X	X	-	X	X
P	Dry flood proofing building	B	-	-	-	-	-	-	-
A	Wet flood proofing building	B	-	-	-	-	-	-	-
A	Raised infrastructure	B	-	-	-	-	-	-	-
A	Floating building	N, F	-	-	-	-	-	-	-
A	Stormwater management	B	-	-	-	-	-	-	-
Managed Retreat	Relocate infrastructure	B	-	-	-	-	-	√	√
Legend: √			Good protection		High recreation value			Enhances sustainability	
-			Neutral		Neutral			Neutral	
x			Causes erosion		Negative impact			Unsustainable	

Table A.4 Generalized regulatory authorities for Atlantic Provinces.

Jurisdictional Responsibility	Province	Regulatory Authority
Environmental Protection	New Brunswick	Department of Environment and Local Government (NB-DELG)
	Nova Scotia	Department of Environment and Climate Change (NS-DECC)
	Prince Edward Island	Department of Environment, Energy, and Climate Action (PEI-DEECA)
	Newfoundland and Labrador	Department of Environment and Climate Change (NL-DECC)
Land Use	New Brunswick	Municipality, NB-DELG
	Nova Scotia	Municipality, Department of Municipal Affairs and Housing (NS-DMAH)
	Prince Edward Island	Municipality, and Department of Agriculture and Land (PEI-DAL)
	Newfoundland and Labrador	Municipality, and Department of Municipal and Provincial Affairs (NL-DMPA)
Parks and Management Areas	New Brunswick	Department of Natural Resources and Energy Development (NB-DNRED) Department of Tourism, Heritage and Culture (NB-DTHC)
	Nova Scotia	Department of Natural Resources and Renewables (NS-DNRR)
	Prince Edward Island	Department of Economic Growth, Tourism, and Culture (PEI-DEGTC), PEI-DEECA
	Newfoundland and Labrador	NL-DECC
Provincial Crown Land	New Brunswick	NB-DNRED
	Nova Scotia	NS-DNRR
	Prince Edward Island	PEI-DEECA
	Newfoundland and Labrador	NL-DMPA
Beaches	New Brunswick	NB-DNRED – Note: the wet part of the beach or beach located between low tide and Ordinary High-Water Mark (High Tide) is considered 'Submerged Crown Land' and under the jurisdiction of NB DNRED. The dry portion of the beach located above the OHWM (high tide) is privately owned.
	Nova Scotia	NS-DNRR
	Prince Edward Island	PEI-DAL, PEI-DEECA
	Newfoundland and Labrador	NL-DECC
Aquaculture	New Brunswick	Department of Agriculture, Aquaculture and Fisheries (NB-DAAF)
	Nova Scotia	Department of Fisheries and Aquaculture (NS-DFA)
	Prince Edward Island	Department of Fisheries and Communities (PEI-FC)
	Newfoundland and Labrador	Department of Fisheries, Forestry and Agriculture NL-DFFA

Table A.5 Typical regulatory requirements for the coastal intervention options.

P – Protect A – Accommodate R – Retreat		Degree of Regulatory Approval Requirements (low, medium, or high)						
		Local government	Provincial				Federal	Cumulative
			NB	PEI	NL	NS		
P	Scour protection	Low	Medium	Medium	Medium	Medium	Medium	Medium
P	Engineered revetment	Low	Medium	Medium	Medium	Medium	Medium	Medium
P	Rip-rap armouring	Low	Medium	Medium	Medium	Medium	Medium	Medium
P	Groynes (groins)	Low	N/A	Medium	Medium	Medium	High	High
P	Shore perpendicular breakwater	Low	Medium	Medium	Medium	Medium	High	High
P	Nearshore breakwaters	Low	Low	Low	Low	Low	High	High
P	Retaining wall	Low	Medium	Medium	Medium	Medium	Medium	Medium
P, A	Artificial reefs	Low	Low	Low	Low	Low	Medium	Medium
P, A	Perched beach (sill)	Low	Low	Low	Low	Low	Medium	Medium
P, A	Beach nourishment	Low	Medium	Medium	Medium	Medium	Medium	Medium
P, A	Plant stabilization	Low	Low	Low	Low	Low	Low	Low
P	Seawall	Low	Medium	Medium	Medium	Medium	Medium	Medium
P	Buried revetment	Low	Medium	Medium	Medium	Medium	Medium	Medium
P, A	Living shoreline/wetland	Low	Medium	Medium	Medium	Medium	Low	Medium
P, A	Dune building	Low	Medium	Medium	Medium	Medium	Low	Medium
P	Dyke	Medium	High	High	High	High	High	High
A	Stormwater management - increase infiltration, conveyance - storage	 Medium Medium	 Low Medium	 Low Medium	 Low Medium	 Low Medium	 Low Low	 Low Medium
A	Dredging	Low	Medium	Low	Medium	Low	High	High
P	Tide barrier/aboiteau	Medium	High	High	High	High	High	High
P	Dry flood proofing building	Medium	Low	Low	Low	Low	Low	Medium
A	Wet flood proofing building	Medium	Low	Low	Low	Low	Low	Medium
A	Raised infrastructure	Medium	Medium	Medium	Medium	Medium	Low	Medium
A	Floating building	Medium	Medium	Medium	Medium	Medium	Low	Medium
R	Relocate infrastructure	High	High	High	High	High	Medium	High

Table A.6 Range of typical construction costs for the coastal intervention options.

P – Protect A – Accommodate R – Retreat		Unit	Typical cost range in Atlantic Canada				Typical maintenance interval		
			< 1,000	1,000 to 5,000	5,000 to 10,000	> 10,000	Short < 5 yrs	Variable	Long 20 yrs +
P, A	Living shoreline/wetland	$/m shoreline	20-40 /m^2						x
P, A	Plant stabilization	$/m shoreline	x				x		
P, A	Dune restoration or stabilization	$/m shoreline		x				x	
P, A	Beach nourishment	$/m shoreline		Local sand source	Offshore sand source			x	
P, A	Perched beach	$/m shoreline			with 1-2 m high rock berm			x	
P, A	Artificial reefs	$/m shoreline		1-2 m high rock berm				x	
P	Revetments	$/m shoreline		Local rock	Distant rock source				x
P	Buried revetment	$/m shoreline		Local rock	Distant rock source			Sand cover	Rock core
P	Rip-rap armouring	$/m road or shoreline	Local rock, typical work (e.g., road repairs)	Distant rock source and/or larger project				x	
P	Groynes	$/m shoreline			Local rock	Distant rock source			x
P	Shore attached breakwater	$/m structure				x			x
P	Detached breakwater	$/m shoreline			Local rock	Distant rock source			x

P	Retaining wall	$/m shoreline		Mechanically stabilized panels	Concrete			x	
P	Seawall	$/m shoreline		Up to 2 m high	2 - 4 m high	> 4 m high			x
P	Dyke	$/m shoreline	Up to 2 m high	2 to 5 m high	5 to 8 m high	> 8 m high			x
P	Scour protection	$/m road or shoreline	Local rock, typical work (e.g., road repairs)	Distant rock source and/or larger project				x	
P	Tide barrier/aboiteau	$100 k to $ 400 k / m^2 hydraulic cross-section				x			x
P	Dry flood proofing building	$/m for waterfront lot width 20 to 30 m		x				x	
A	Wet flood proofing building						x		
A	Raised infrastructure	$/m (road, or waterfront lot width 20 to 30 m)		x				x	
A	Floating building	$/m for waterfront lot			Lot width 20 to 30 m	Lot width <20 m			x
A	Stormwater management								
A	Drainage ditch	$/m ditch	x						x
A	Detainment pond	$/m^3$	x						x
A	Rain garden	$/m^2$	20-40/m^2						x
R	Relocate infrastructure	$/m shoreline		Road $/m		Waterfront lot up to 30 m			x

Note: Land acquisition $ not included in any of the options