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ADAPTING TO CLIMATE CHANGE IN COASTAL COMMUNITIES OF THE ATLANTIC PROVINCES, CANADA:

LAND USE PLANNING AND ENGINEERING AND NATURAL APPROACHES

PART 3 ENGINEERING TOOLS ADAPTATION OPTIONS

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SOLUTIONS D'ADAPTATION AUX CHANGEMENTS CLIMATIQUES POUR L'ATLANTIQUE

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Adapting to Climate Change in Coastal Communities of the Atlantic Provinces, Canada: Land Use Planning and Engineering and Natural Approaches

Prepared for ACASA (Atlantic Climate Adaptation Solutions Association)

No. AP291: Coastal Adaptation Guidance – Developing a Decision Key on Planning and Engineering Guidance for the Selection of Sustainable Coastal Adaptation Strategies.

Part 1 Guidance for Selecting Adaptation Options

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PREFACE

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 in the coastal zone.

Adapting to Climate Change in Coastal Communities of the Atlantic Provinces, Canada 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 Atlantic Climate Adaptation Solutions Association (ACASA) web-based Coastal Community Adaptation Tool, and the associated Community Profile for identifying community capacity for adaptation. Combined, these resources help decision-makers define their coastal climate change adaptation needs and select the most appropriate land use planning or engineering tools 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 ACASA web-based Coastal Community 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 Engineering Tools Adaptation Options, presents over two dozen engineering tools 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 using engineering as an adaptation approach. The tools and examples in this volume are the engineering options of the ACASA web-based Coastal Community Adaptation Tool.

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CHAPTER 1: INTRODUCTION

Adapting to Climate Change in Coastal Communities of the Atlantic Provinces, Canada: Land Use Planning and Engineering and Natural Approaches, Part 3 Engineering Tools Adaptation Options presents over two dozen engineering tools available for managing the climate change impacts of coastal flooding and erosion. The additional guidance documents in this set are *Part 1 Guidance for Selecting Adaptation Options* and *Part 2 Land Use Planning Adaptation Tools Options.* Together, these documents provide foundation information to support decisions about climate change adaptation for coastal systems of the Atlantic Provinces. The information in this set of guidance documents will help decision-makers select land use planning tools and engineering tools that are appropriate for the community.

This summary guidebook is intended as an informative checklist to evaluate potential solutions. It is not a design guideline and it is not a substitute for site-specific professional engineering and planning advice.

Part 3 Engineering Tools Adaptation Options begins with a summary of adaptation and of the relationship between climate change, coastal processes and coastal risk. It is the objective 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.

The focus of *Part 3 Engineering Tools Adaptation Options* is the inventory of engineering tools, 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.

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:

- *Sea Level Rise Adaptation Primer – A Toolkit to Build Adaptive Capacity on Canada's South Coasts* (British Columbia Ministry of Environment, 2013).
- *StormSmart Properties Comparison Chart – Relative Costs of Shoreline Stabilization Options.* (State of Massachusetts, 2014).
- *Technologies for Climate Change Adaptation: Coastal Erosion and Flooding* (Linham & Nicholls, 2010).
- *Adaptation Options for Human Settlements in South East Queensland, Australia – Supplementary Report* (Choy, Serrao-Neumann, Crick, Schuch, Sanò, van Staden, Sahin, Harman, Baum, 2012).

Chapter 2: 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. Five strategies for adaptation are Avoid, Retreat, Accommodate, Protect or Procedural. They are summarized here. More information about these strategies is found in *Part 1: Guidance for Selecting Adaptation Options.*

2.1 Consequence-Reduction Strategies

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 risk 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 'Retreat the line', 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 is used in place 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 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 abandon. Abandon does not involve pre-planned relocation. Abandon may be necessary in emergency situations if no other options exist.

Accommodate, or 'Raise the line', allows for continual use of coastal lands but changes the use of the land or the current infrastructure. Changes in land use may be from uses that do not need access to the water to uses that do need water access. Changes to infrastructure may include designing to accommodate flooding with raised, flood proofed or floating structures.

2.2 Hazard Reduction Strategies

Protect, or 'Advance' or 'Hold the line', is often a reaction to coastal erosion or flooding. Protect is the most common form of adaptation in coastal areas throughout the world. It almost always involves some kind of engineering 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. Ideally hard and soft measures should be combined to integrate ecological and engineering design perspectives.

These strategies are not mutually exclusive; adaptation often involves a combination of approaches.

2.3 Overarching Strategies

Procedural approaches 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. and education program) but they usually support the other strategies or provide an overarching framework for adaptation planning.

2.4 Coastal Processes, Climate Change and Engineering Considerations

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.

In summary, the goal of engineering strategies is to manage or reduce coastal hazard – 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, 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 2.1).

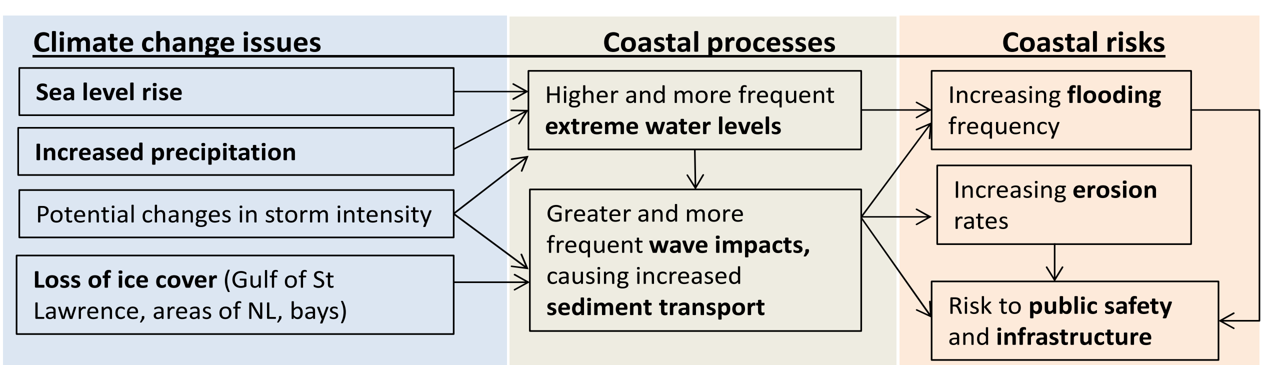


Figure 2.1 Climate change impacts on coastal hazards. (Image Source: Vincent Leys, CBCL Limited)

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.

Chapter 3: Inventory of Engineering Adaptation Tools

3.1 Summary Tables

Two-dozen engineering tools were identified with relevance to adaptation in the Atlantic Provinces. Each of the engineering tool options are summarized in the following tables. Some of the tools outlined in this document cover more than one of the adaptation approaches described above.

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

The engineering tools 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. Table 3.1 presents the engineering tools and typical application by coastal type, or system (See also *Part 1: Guidance for Selecting Adaptation Options*). Table 3.2 shows the pairing of tools with site characteristics, specifically wave height and exposure, sediment supply requirements and shore slope. Table 3.3 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 3.4 summarizes the compatibility between the tools.

Use the following tables for an initial screening of options, then see the individual tool descriptions in the next Chapter.

TABLE 3.1 ENGINEERING TOOLS AND TYPICAL APPLICATION BY COASTAL TYPE

			PREVAILING COASTAL TYPE & APPLICATION								
			Coastal region	Estuary	Salt marsh	Coastal sandy system	Cobble beach	Cliff/ bluff	Rock shore	Built	Existing dykelands
			Atlantic seaboard - NS, NL	■	■	■	■	■	■	■	
			Bay of Fundy - NS, NB	■	■		■	■	■	■	■
			Gulf of St Lawrence and Northumberland Strait - NS, PEI	■	■	■		■		■	
TOOLS	Erosion Mitigation	P	Scour protection	■	■	■	■	■		■	■
TOOLS	Erosion Mitigation	P	Engineered revetment	■		■	■	■		■	■
TOOLS	Erosion Mitigation	P	Rip-rap armouring	■	■			■		■	■
TOOLS	Erosion Mitigation	P	Groynes (groins)			■					
TOOLS	Erosion Mitigation	P	Shore perpendicular breakwater		■	■	■			■	
TOOLS	Erosion Mitigation	P	Nearshore breakwaters		■	■	■	■		■	
TOOLS	Erosion Mitigation	P	Retaining wall	■	■			■		■	
TOOLS	Erosion Mitigation	P, A	Artificial reefs	■	■	■	■	■			
TOOLS	Erosion Mitigation	P, A	Perched beach (sill)	■	■	■	■	■			
TOOLS	Erosion Mitigation	P, A	Beach nourishment			■	■	■			
TOOLS	Erosion Mitigation	P, A	Plant stabilization	■	■	■		■			■
TOOLS	Erosion & Flood Mitig.	P	Seawall	■	■	■	■	■	■	■	
TOOLS	Erosion & Flood Mitig.	P	Buried revetment			■	■				
TOOLS	Erosion & Flood Mitig.	P, A	Living shoreline/wetland	■	■	■	■	■			
TOOLS	Erosion & Flood Mitig.	P, A	Dune building			■					
TOOLS	Flood Mitigation	P	Dyke	■	■	■	■		■		■
TOOLS	Flood Mitigation	A	Dredging	■		■					■
TOOLS	Flood Mitigation	A	Bluff drain					■			
TOOLS	Flood Mitigation	A	Stormwater management (also includes drainge ditch, detainment pond, and rain garden)	■	■	■	■	■	■	■	■
TOOLS	Flood Mitigation	P	Tide barrier/aboiteau	■	■	■	■	■	■	■	■
TOOLS	Flood Mitigation	P	Dry flood proofing building	■	■	■	■	■	■	■	■
TOOLS	Flood Mitigation	A	Wet flood proofing building	■	■	■	■	■	■	■	■
TOOLS	Flood Mitigation	A	Raised infrastructure	■	■	■	■	■	■	■	■
TOOLS	Flood Mitigation	A	Floating building	■	■	■	■	■	■	■	■
TOOLS	Retreat		Relocate infrastructure	■	■	■	■	■	■	■	■

P - Protect

A-Accommodate

R - Retreat

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

TABLE 3.2 ENGINEERING TOOLS AND TYPICAL APPLICATION BY WAVE EXPOSURE[1]

				BEST CONDITIONS FOR APPLICATION				
				Wave characteristics		Sediment supply required?		Maximum slope (degrees)
				Maximum wave exposure	Wave crest angle	Initial fill	Natural background supply	
TOOLS	Erosion Mitigation	P	Scour protection	Protected				40
		P	Engineered revetment	Exposed				35
		P	Rip-rap armouring	Protected				40
		P	Groynes	Exposed	At an angle to shore	yes		
		P	Shore perpendicular breakwater	Exposed	At an angle to shore			
		P	Nearshore breakwaters	Exposed		yes		
		P	Retaining wall	Protected				90
		P, A	Artificial reefs	Moderate				
		P, A	Perched beach (sill)	Moderate	Parallel to shore	yes	yes	
		P, A	Beach nourishment	Moderate		yes	yes	
		P, A	Plant stabilization	Protected				60
	Erosion & Flood Mitig.	P	Seawall	Exposed		yes		90
		P	Buried revetment	Exposed		yes	yes	35
		P, A	Living shoreline/wetland	Protected		yes		10
		P, A	Dune building	Exposed		yes	yes	20
	Flood Mitigation	P	Dyke	Exposed				25
		A	Dredging	Protected			no, avoid	
		A	Bluff drain	Exposed				
		A	Stormwater management	N/A				
		P	Tide barrier/aboiteau	Moderate				
		P	Dry flood proofing building	Protected				
		A	Wet flood proofing building	Protected				
		A	Raised infrastructure	Protected				
		A	Floating building	Protected				
	Retreat		Relocate infrastructure	Exposed				

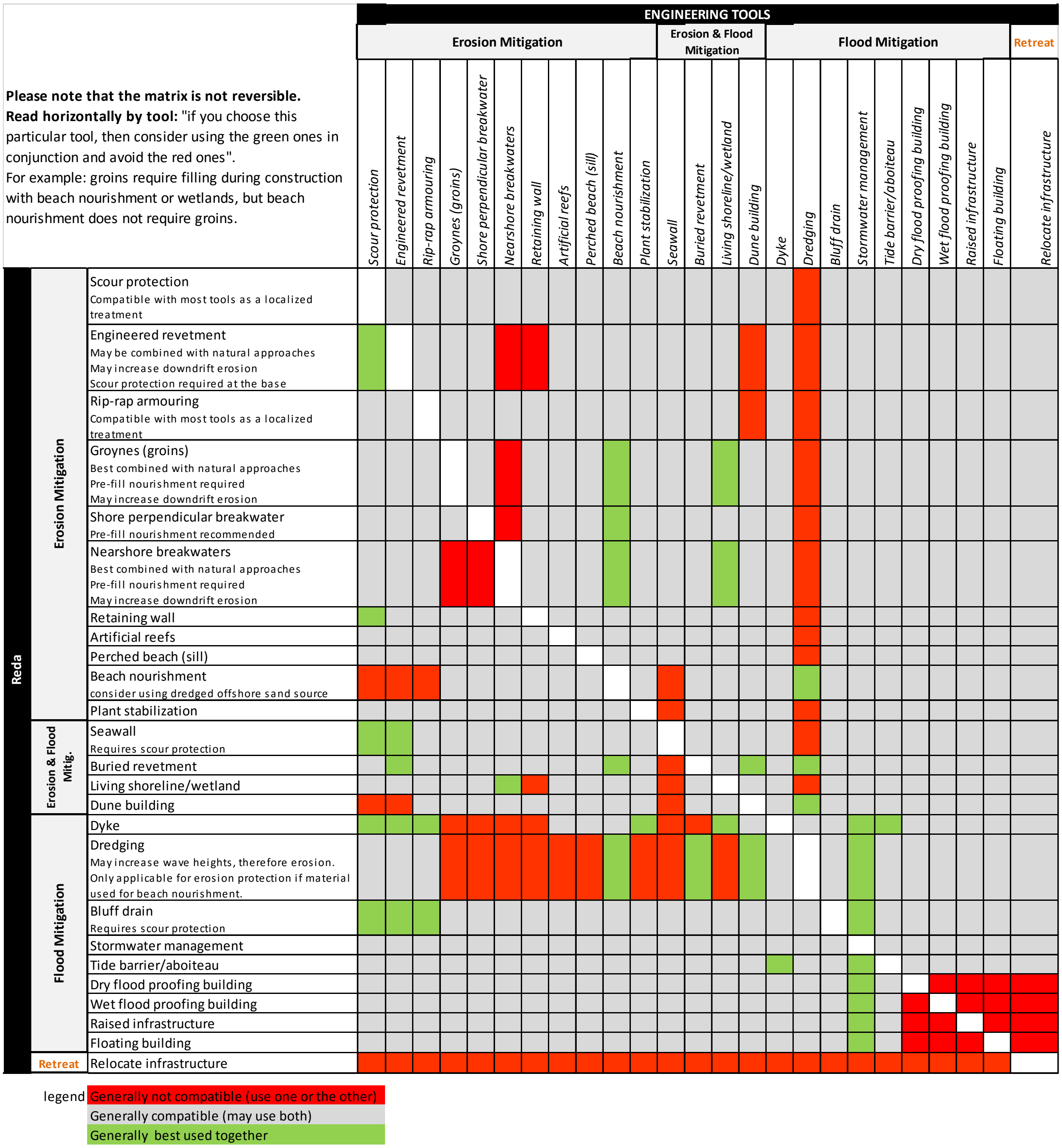
Wave exposure	Significant wave height	Distance of open water experiencing a sustained wind
Protected	< 1 m	< 5 km
Moderate	1 to 3 m	5 to 50 km
Exposed	3 m +	50 km +

TABLE 3.3 FUNCTIONAL CHARACTERISTICS OF ENGINEERING TOOLS[2,3]

ADAPTIVE RESPONSES AND TOOLS			Typ. 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
Erosion Mitigation	P	Scour protection	F	√	X	X	X	-	X	-
Erosion Mitigation	P	Engineered revetment	F, B	√	X	X	X	-	X	-
Erosion Mitigation	P	Rip-rap armouring	F, B	√	X	X	X	-	X	-
Erosion Mitigation	P	Groynes	N	√	√	X	X	X	X	-
Erosion Mitigation	P	Shore perpendicular breakwater	N	√	√	-	X	X	X	-
Erosion Mitigation	P	Nearshore breakwaters	N	√	√	X	X	X	X	-
Erosion Mitigation	P	Retaining wall	B	√	-	-	X	-	X	-
Erosion Mitigation	P, A	Artificial reefs	N	√	√	-	√	X	X	√
Erosion Mitigation	P, A	Perched beach (sill)	N	-	√	√	√	X	X	-
Erosion Mitigation	P, A	Beach nourishment	B	√	√	√	√	-	X	-
Erosion Mitigation	P, A	Plant stabilization	B	√	√	-	√	-	-	√
Erosion & Flood Mitig.	P	Seawall	B	√	X	X	X	-	X	-
Erosion & Flood Mitig.	P	Buried revetment	B	√	√	√	√	-	X	-
Erosion & Flood Mitig.	P, A	Living shoreline/wetland	F, B	-	√	-	√	-	√	√
Erosion & Flood Mitig.	P, A	Dune building	B	√	√	-	√	-	X	√
Flood Mitigation	P	Dyke	F	-	-	-	X	-	X	X
Flood Mitigation	A	Dredging	F	-	X	X	X	-	X	X
Flood Mitigation	A	Bluff drain	B	-	-	-	-	-	-	-
Flood Mitigation	A	Stormwater management	B	-	-	-	-	-	-	-
Flood Mitigation	P	Tide barrier/aboiteau	F	√	-	-	-	-	X	X
Flood Mitigation	P	Dry flood proofing building	B	-	-	-	-	-	-	-
Flood Mitigation	A	Wet flood proofing building	B	-	-	-	-	-	-	-
Flood Mitigation	A	Raised infrastructure	B	-	-	-	-	-	-	-
Flood Mitigation	A	Floating building	N, F	-	-	-	-	-	-	-
Retreat		Relocate infrastructure	B	-	-	-	-	-	√	√

Legend		Protection	Potential Impacts	Potential Long-Term Sustainability
	√	Good protection	High recreation value	Enhances sustainability
	-	Neutral	Neutral	Neutral
	X	Causes erosion	Negative impact	Unsustainable

TABLE 3.4 GENERAL COMPATIBILITY OF ENGINEERING TOOLS



3.2 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 tool will impact the natural environment).

Consider regulatory requirements and timelines, particularly for engineered options in environmentally sensitive areas with public concern.

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 m seaward.[4] The *Ocean Act* further divides the maritime zone into the following regions:[5]

- 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. 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.

In accordance to 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.[6] 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 3.5 details generalized jurisdictional responsibility and the corresponding regulatory authorities for each Atlantic Canadian province.

Provincial coastal protection policies have been established for New Brunswick, Nova Scotia and Newfoundland and Labrador. Provincial coastal protection policies are implemented where provincial regulatory approvals are required. The implementation of these policies can affect the costs and timelines associated with regulatory permitting processes. The following policies are in effect:

- NB – Coastal Areas Protection Policy,
- PEI – Municipal and Provincial Land Use Policies,[i]
- NS – Coastal Management Framework, and
- NL – Coastal and Ocean Management Strategy and Policy Framework.

[i] There is currently no overarching land use or coastal land use policy in PEI. Coastal Protection is regulated under the *Environmental Protection Act* which is enforced by the Department of Communities, Land and Environment. A Watercourse, Wetland and Buffer Zone Activity Permit is required for conducting certain activities near the coastline.

TABLE 3.5 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	Nova Scotia Environment (NSE)
	Prince Edward Island	Department of Communities, Land and Environment (PEI-DCLE) and Transportation, and Energy (PEI-TIE)
	Newfoundland and Labrador	Department of Environment and Conservation (NL-DEC)
Land Use	New Brunswick	Municipality
	Nova Scotia	Municipality
	Prince Edward Island	Municipality and Department of Communities, Land and Environment (PEI-DCLE)
	Newfoundland and Labrador	Municipality
Parks and Management Areas	New Brunswick	Department of Natural Resources (NB-DNR) Department of Tourism, Heritage and Culture
	Nova Scotia	NS-DNR
	Prince Edward Island	Department of Communities, Land and Environment (PEI-DCLE), Department of Economic Development and Tourism (PEI-EDT), PEI-DCLE and PEI-TIE
	Newfoundland and Labrador	NL-DEC
Provincial Crown Land	New Brunswick	NB-DNR
	Nova Scotia	NS-DNR
	Prince Edward Island	PEI-DCLE (sp) and PEI-TIE
	Newfoundland and Labrador	Department of Municipal and Intergovernmental Affairs (NL-MIGA)
Beaches	New Brunswick	NB-DNR – 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 DNR. The dry portion of the beach located above the OHWM (high tide) is privately owned.
	Nova Scotia	NS-DNR
	Prince Edward Island	PEI-DCLE, PEI-TIE and PEI-EDT
	Newfoundland and Labrador	NL-DEC
Aquaculture	New Brunswick	Department of Agriculture, Aquaculture and Fisheries
	Nova Scotia	Department of Fisheries and Aquaculture
	Prince Edward Island	Department of Agriculture and Fisheries (PEI-AF) PEI-DCLE and PEI-TIE
	Newfoundland and Labrador	Department of Fisheries and Aquaculture

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 engineering options is based exclusively on the impact each tool 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 web-based decision-support tool, *Coastal Community Adaptation Tool*. Departments to contact for permitting are listed in Table 3.5.

Table 3.6 Typical regulatory requirements for engineering tools

Adaptive responses and tools			Degree of Regulatory Approval Requirements (low, medium or high): Local government	Provincial: NB	Provincial: PEI	Provincial: NL	Provincial: NS	Federal	Cumulative
Erosion Mitigation	P	Scour protection	Low	Medium	Medium	Medium	Medium	Medium	Medium
Erosion Mitigation	P	Engineered revetment	Low	Medium	Medium	Medium	Medium	Medium	Medium
Erosion Mitigation	P	Rip-rap armouring	Low	Medium	Medium	Medium	Medium	Medium	Medium
Erosion Mitigation	P	Groynes (groins)	Low	Not permitted	Medium	Medium	Medium	High	High
Erosion Mitigation	P	Shore perpendicular breakwater	Low	Medium	Medium	Medium	Medium	High	High
Erosion Mitigation	P	Nearshore breakwaters	Low	Low	Low	Low	Low	High	High
Erosion Mitigation	P	Retaining wall	Low	Medium	Medium	Medium	Medium	Medium	Medium
Erosion Mitigation	P, A	Artificial reefs	Low	Low	Low	Low	Low	Medium	Medium
Erosion Mitigation	P, A	Perched beach (sill)	Low	Low	Low	Low	Low	Medium	Medium
Erosion Mitigation	P, A	Beach nourishment	Low	Medium	Medium	Medium	Medium	Medium	Medium
Erosion Mitigation	P, A	Plant stabilization	Low	Low	Low	Low	Low	Low	Low
Erosion & Flood Mitig.	P	Seawall	Low	Medium	Medium	Medium	Medium	Medium	Medium
Erosion & Flood Mitig.	P	Buried revetment	Low	Medium	Medium	Medium	Medium	Medium	Medium
Erosion & Flood Mitig.	P, A	Living shoreline/wetland	Low	Medium	Medium	Medium	Medium	Low	Medium
Erosion & Flood Mitig.	P, A	Dune building	Low	Medium	Medium	Medium	Medium	Low	Medium
Flood Mitigation	P	Dyke	Medium	High	High	High	High	High	High
Flood Mitigation	A	Bluff drain	Low	Low	Low	Low	Low	Low	Low
Flood Mitigation	A	Stormwater management							
Flood Mitigation	A	- increase infiltration, conveyance (drainage ditch)	Low	Low	Low	Low	Low	Low	Low
Flood Mitigation	A	- storage (detainment pond)	Medium	Medium	Medium	Medium	Medium	Low	Medium
Flood Mitigation	A	- rain garden	Low	Low	Low	Low	Low	Low	Low
Flood Mitigation	A	Dredging	Low	Medium	Low	Medium	Low	High	High
Flood Mitigation	P	Tide barrier/aboiteau	Medium	High	High	High	High	High	High
Flood Mitigation	P	Dry flood proofing building	Medium	Low	Low	Low	Low	Low	Medium
Flood Mitigation	A	Wet flood proofing building	Medium	Low	Low	Low	Low	Low	Medium
Flood Mitigation	A	Raised infrastructure	Medium	Medium	Medium	Medium	Medium	Low	Medium
Flood Mitigation	A	Floating building	Medium	Medium	Medium	Medium	Medium	Low	Medium
Retreat		Relocate infrastructure	High	High	High	High	High	Medium	High

P - Protect
A-Accommodate
R - Retreat

3.3 Basic Coast Considerations

Costs and materials used in each tool can vary greatly depending on site conditions. 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. The price for rip rap and armour stone ranges from $20 per tonne to $100 per tonne depending on quantities needed and the location of a project.

Typical cost ranges and maintenance intervals for engineering options were developed based on feedback from engineers at various levels of government, local experience, and literature sources. The results are summarized in Table 3.7. This table should be used with caution as a preliminary screening tool only. Whenever possible or applicable, cost ranges are given per unit metre of shoreline to allow comparison of various options on a similar scale.

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

The following costs have not been included in any of the options:

- land and right of way acquisition,
- inflation post-year 2014,
- 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 for engineering tools for coastal adaptation in Table 3.7 are presented on the basis of experience, qualifications, and best judgment; have been prepared in accordance with acceptable principles and practices; are intended for comparative purposes only between the tools in this guidebook; and are not intended for pricing of a specific project in a specific area.

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.

TABLE 3.7 RANGE OF TYPICAL CONSTRUCTION COSTS FOR ENGINEERING TOOLS

			Typical cost range in Atlantic Canada					Typical maintenance interval		
			Unit	< 1,000	1,000 to 5,000	5,000 to 10,000	> 10,000	Short < 5 yrs	Variable	Long 20 yrs +
Erosion Mitigation	P	Scour protection	$/m road or shoreline	Local rock, typical work (e.g. road repairs)	Distant rock source and/or larger project				x	
	P	Rip-rap armouring								
	P	Engineered revetment	$/m shoreline		Local rock	Distant rock source				x
	P	Groynes	$/m shoreline			Local rock	Distant rock source			x
	P	Shore perpendicular breakwater	$/m structure				x			x
	P	Nearshore breakwater	$/m shoreline			Local rock	Distant rock source			x
	P	Retaining wall	$/m shoreline		Mechanically stabilized panels	Concrete			x	
	P, A	Artificial reefs	$/m shoreline		1-2 m high rock berm				x	
	P, A	Perched beach (sill)	$/m shoreline			with 1-2 m high rock berm			x	
	P, A	Beach nourishment	$/m shoreline		Local sand source	Offshore sand source			x	
	P, A	Plant stabilization	$/m shoreline	x				x		
Erosion & Flood Mitig.	P	Seawall	$/m shoreline		Up to 2 m high	2 - 4 m high	> 4 m high			x
	P	Buried revetment	$/m shoreline		Local rock	Distant rock source			Sand cover	Rock core
	P, A	Living shoreline/wetland	$/m shoreline	20-40 /m2						x
	P, A	Dune building	$/m shoreline		x				x	
Flood Mitigation	P	Dyke	$/m shoreline	Up to 2 m high	2 to 5 m high	5 to 8 m high	> 8 m high			x
	A	Bluff drain		x					x	
	A	Stormwater management								
		Drainage ditch	$/m ditch	x						x
		Storage (detainment pond)	$/m3	x						x
		Rain garden	$/m2	20-40 /m2						x
	P	Tide barrier/aboiteau	$100 k to $ 400 k / m2 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
Retreat		Relocate infrastructure	$/m shoreline		Road $/m		Waterfront lot up to 30 m $/m			x
				Land acquisition $ not included in any of the options						

P - Protect
A-Accommodate
R - Retreat

3.4 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 3.8 summarizes the basic engineering strategies to account for climate change. The strategies most applicable to each engineering tool are listed in Table 3.9.

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.

Table 3.8 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 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 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 - Retreat	

TABLE 3.9 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.
Erosion Mitigation	Scour protection		
	Engineered revetment	-	
	Rip-rap armouring		
	Groynes (groins)	-	
	Shore perpendicular breakwater	-	
	Nearshore breakwaters	-	
	Retaining wall	-	
	Artificial reefs		
	Perched beach (sill)	-	
	Beach nourishment		-
	Plant stabilization		-
Erosion and Flood Mitig.	Seawall	-	
	Buried revetment	-	
	Living shoreline/wetland		
	Dune building		-
Flood Mitigation	Dyke	-	
	Dredging		-
	Bluff drain		
	Stormwater management (drainage ditch, detainment pond, rain garden)		
	Tide barrier/aboiteau	-	
	Dry flood proofing building	-	
	Wet flood proofing building	-	
	Raised infrastructure	-	
	Floating building	-	
Retreat	Relocate infrastructure	-	

3.5 Next Steps

Table 3.10 provides general guidance on the information and professional expertise required for implementing each engineering tool. Assistance for these next steps can typically be provided by a combination of provincial government and engineering consultants if required.

Table 3.10 Typical information and expertise required for engineering tool implementation

			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*	*Civil Engineer with geotechnical expertise*	*Civil Engineer with coastal expertise*	*Civil Engineer with water resources expertise*	*Marine/aquatic biologist*
ENGINEERING TOOLS	**Erosion Mitigation**	Scour protection	■	■			■	■	■	■	■				
		Engineered revetment	■	■	■		■	■	■	■			■		
		Rip-rap armouring	■	■	■		■	■	■	■	■				
		Groynes (groins)		■	■		■	■	■	■			■		
		Shore perpendicular breakwater		■	■		■	■	■	■			■		
		Nearshore breakwaters		■	■		■	■	■	■			■		
		Retaining wall	■		■		■					■			
		Artificial reefs		■				■	■				■		■
		Perched beach (sill)		■	■		■	■		■			■		
		Beach nourishment	■	■	■		■	■		■			■		
		Plant stabilization	■		■		■	■							■
	Erosion & Flood Mitig.	Seawall	■	■	■	■	■	■				■	■		
		Buried revetment	■	■	■	■	■	■		■			■		
		Living shoreline/wetland	■	■	■	■	■	■					■		■
		Dune building	■		■	■	■	■		■			■		
	Flood Mitigation	Dyke	■			■	■	■				■	■	■	
		Dredging	■			■	■		■	■		■	■	■	
		Bluff drain	■			■	■		■			■		■	
		Stormwater management (also includes drainge ditch, detainment pond, and rain garden)	■			■	■		■					■	
		Tide barrier/aboiteau	■	■		■	■	■	■			■	■	■	
		Dry flood proofing building	■			■	■				■				
		Wet flood proofing building	■			■	■				■				
		Raised infrastructure	■			■	■				■				
		Floating building	■			■	■				■				
	Retreat	Relocate infrastructure	■			■	■				■				

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[1] Mangor, K. (2004). *Shoreline Management Guidelines*. Published by DHI Water and Environment, Horsholm, Denmark. ISBN 87-981950-5-0

[2] Ibid.

[3] PIANC. (2014). *Countries in Transition: Coastal Erosion Mitigation Guidelines*. The World Association for Waterborne Transport Infrastructure. Report n. 123

[4] 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

[5] 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

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

CHAPTER 4: ENGINEERING TOOLS ADAPTATION OPTIONS

This section presents over two dozen engineering tools for use in coastal climate change adaptation. Presentation of each tool includes a description and examples of how the tool is used. This information is for general education purposes, to help the reader evaluate potential solutions.

Examples were collected from the work experience of the authors, supplemented by literature sources. They stand as general illustrations of each engineering tool 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.

While the authors made every effort to source the most reliable information, it could not always be verified. This information is not a substitute for site-specific professional advice. CBCL Limited and the authors make no representation as to its accuracy and the claims made by the articles from which it was derived.

4.1 Maintenance, Repair or Replacement of Existing Structure

Coastal risk		Adaptive response			
Erosion	Flooding	Retreat	Accommodate	Protect	
				Hard structure	Soft approach

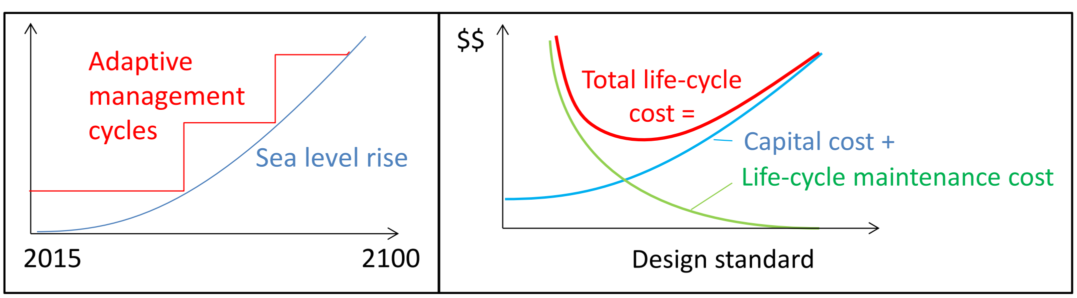
Case 1: Structure is experiencing damage

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.



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

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, 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 sink holes	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 stabilization structures
Dyke	Erosion	Add rock protection
	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 road/building

Note: also consider alternative tools (relocation 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.

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
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 tools (relocation or other) before undertaking significant maintenance.

4.2 Scour Protection

Coastal risk		Adaptive response			
Erosion	Flooding	Retreat	Accommodate	Protect	
				Hard structure	Soft approach

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.

Scour protection at Cheticamp Bridge piers using rock (left), and along tidal Shubenacadie River, NS (middle and right) using rock-filled gabion mats. (Image Sources: CBCL Limited)

OPPORTUNITIES	CONSTRAINTS
• 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).	• 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.

4.3 Engineered Revetment

Coastal risk		Adaptive response			
Erosion	Flooding	Retreat	Accommodate	Protect	
				Hard structure	Soft approach

Engineered revetments can be made from rock, concrete panels, wood frames or corrosion-resistant wire-mesh filled with rock referred to as gabions. Gabions allow a smaller-sized stone to be used. Revetments can be combined with another tool 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. 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.

Construction of a revetment at Sydney Harbour, NS, confined disposal facility. (Image Source: Vincent Leys, CBCL Limited)

OPPORTUNITIES	CONSTRAINTS
• 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.	• 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.

ENGINEERED REVETMENT COMBINED WITH LIVING SHORELINES EXAMPLE (INTERNATIONAL)

Mathews County, Chesapeake Bay, Virginia

Profile	
Coast	Chesapeake Bay, Atlantic
Region	Virginia
Wave Climate	Medium to Low
Municipal Type	County
Population	8,978 (2010)
Project Area	223 km (shoreline)
Year	2011
Funding/Costs	Private Landowners and Keith Campbell Foundation

Summary – Mathews County is located on Chesapeake Bay, Virginia, and is surrounded almost entirely by water. It is bordered by the Piankatank River to the west and Mobjack Bay to the south. Coastal restoration projects at seven sites located throughout the County used engineered revetments in combination with restoring natural coastal environments ("Living Shoreline" restoration). The seven sites had different wave climates: two projects were in high wave impact areas, three in medium impact and two in low impact wave environments. Of the seven sites, six already had naturally occurring salt marshes and the seventh was planted during the restoration process.

The engineered revetments are low-profile in design to match the relative position and height of the marsh surface. They are located close to shore in intertidal areas. The tidal marshes protected by these structures were either naturally occurring or constructed. Marshes are constructed by placing fill on the land side of the revetment and planting marsh plants in the tidal zone.[1,2,3]

Project Impacts – Revetments were effective in areas with medium to low wave energy, but less effective in high wave energy areas and during extreme storm events. The revetments were very effective for both upland and marsh erosion control. The upland bank erosion that was observed before the structures were constructed was reduced.[4]

EXAMPLES OF LIVING SHORELINES WITH STRATEGIC ROCK STABILIZATION. (IMAGE SOURCE: DUHRING, BARNARD & HARDAWAY[5])

[1] Hardaway, C.S, & Gunn, J.R. (2011). A brief history of headland breakwaters for shore protection in Chesapeake Bay, USA. Shore & Beach. Vol. 78, No. 4/Vol. 79, No. 1

[2] Hardaway, C.S., Milligan, D.A., & Duhring, K. (2010). Living Shoreline Design Guidelines for Shore Protection in Virginia's Estuarine Environments. Version 1.2. Special Report in Applied Marine Science and Ocean Engineering. No. 421. Virginia Institute of Marine Science

[3] Erdle, S.Y., Davis, J.L.D, & Sellner, K.G. (2006). Management, Policy, Science, and Engineering of Nonstructural Erosion Control in the Chespeake Bay - Proceedings of the 2006 Living Shoreline Summit

[4] Ibid.

[5] Duhring, K.A., Barnard, T.A., & Hardaway, S. (2006). A Survey of the Effectiveness of Existing Marsh Toe Protection Structures in Virginia. Virginia Institute of Marine Science

4.4 Rip-rap Armouring

Coastal risk		Adaptive response			
Erosion	Flooding	Retreat	Accommodate	Protect	
				Hard structure	Soft approach

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, waste concrete, 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.

Rip-rap slope at Kingsport, NS, on the Bay of Fundy. (Image Source: Bruce Higgins, CBCL Limited)

OPPORTUNITIES	CONSTRAINTS
• 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).	• 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.

4.5 Groynes

Coastal risk		Adaptive response			
Erosion	Flooding	Retreat	Accommodate	Protect	
				Hard structure	Soft approach

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).

Low-crested groynes at Dingwall, NS. (Image Source: Vincent Leys, CBCL Limited)

OPPORTUNITIES	CONSTRAINTS
• 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.	• Usefulness is restricted to areas with sand beaches with an oblique wave climate causing longshore drift. • Only reduces erosion on one side of the groyn (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.

GROYNE EXAMPLE (INTERNATIONAL)

Mimicking Natural Protection, Beach Park, Hau‘ula, Hawaii

Profile	
Coast	Pacific
Region	O’ahu, Hawaii
Wave Climate	High
Municipal Type	Village
Population	4,148 (2010)
Project Area	110 m (Beach)
Year	2014

Summary – In order to slow erosion and increase growth of Beach Park in Hau‘ula, Hawaii, natural groyne-like structures were engineered to extend from the reef to the shore. The natural features are made of rubble and respond in a dynamic way: they shift and move with wave action. The groynes are 200–400 feet long with a low elevation. The shape is similar to a T, with a larger termination (the ‘head’ of the structure). The wave-facing side has a very flat slope and the opposite side is steep. The groyne is made of stone averaging one to four inches in size mixed with sand and scattered stone up to one foot in size.[1]

GROYNE-LIKE STRUCTURES IN KIHEI, MAUI, HI. (IMAGE SOURCE: GOOGLE EARTH[2])

Context – The undeveloped shoreline was in front of private residences with seawalls for protection. The seawalls limited the amount of sand in front of the properties. The narrow beach extends landward to a coastal highway which flooded during high tides. The highway is protected by randomly dumped boulders and concrete piles. A wide reef extends along the coast at a depth of 12 feet, and is located approximately 2,500 feet offshore. The shallow reef bottom is a mixture of rubble, sand, and scattered reef over a hard bottom.

The expectation is that the groynes, combined with the natural breakwater of the reef, will help increase sediment build up on the beach.

NATURAL REEF BREAKWATER AND GROYNES AT HAU'ULA, O'AHU. (IMAGE SOURCE: GOOGLE EARTH[3])

[1] Smith, T.D., & Sullivan, S. (2005). Innovative shore protection in Hawaii. *Proceedings of the 14th Biennial Coastal Zone Conference*. New Orleans, Louisiana. July 17 to 21, 2005.

[2] Google Earth. (n.d.). *Image of Hau'ula, O'ahu*. [image]. Retrieved from https://www.google.com/earth/

[3] Ibid.

4.6 Shore Perpendicular Breakwater

Coastal risk		Adaptive response			
Erosion	Flooding	Retreat	Accommodate	Protect	
				Hard structure	Soft approach

Shore perpendicular 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.

Breakwaters at Skinners Pond, Prince Edward Island. (Image Source: Vincent Leys, CBCL Limited)

OPPORTUNITIES	CONSTRAINTS
• 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).	• 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.

Breakwater Example (International)

Port Oriel Attached Breakwater, Clogherhead, Ireland

Profile	
Coast	Irish Sea
Region	Ireland
Wave Climate	High
Municipal Type	Town
Population	1558 (2006)
Project Area	180 m (quay)
Year	2005-2006
Funding/Costs	Part of a $2.85 million USD port restoration

Summary – This project involved the reconstruction of a fishing port in Clogherhead, Ireland. The port was built in 1885 and consisted of a small basin and a breakwater. Port Oriel is exposed to direct wave attack from the east and northeast. Upon completion of the new breakwater, the port now has a 180 m wharf behind a breakwater composed of an Xbloc (x-shaped concrete units) armour layer (shown in the figure below). The project began in July 2005 and was completed December 2006. The breakwater was made with 1450 individual xblocs each 4 m^3 in size.

Completed breakwater with Xbloc armour layer at Port Oriel. (Image Source: Xbloc[1])

[1] xbloc. (n.d.). *Xbloc at Port Oriel*. [image]. Retrieved from http://www.xbloc.com/projects/breakwater-port-oriel-ireland/item577

4.7 Nearshore Breakwaters

Coastal risk		Adaptive response			
Erosion	Flooding	Retreat	Accommodate	Protect	
				Hard structure	Soft approach

Nearshore 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. Nearshore 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.

Nearshore breakwater at Pointe Sapin, New Brunswick, acting as a sand trap. (Image Source: Google Earth[1])

OPPORTUNITIES	CONSTRAINTS
• 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.	• 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.

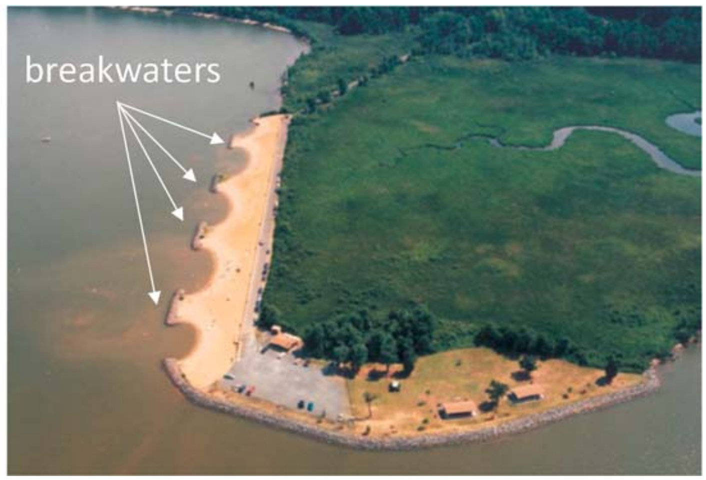
NEARSHORE BREAKWATERS EXAMPLE (INTERNATIONAL)

Aquia Landing County Park, Stafford County, Virginia

Profile	
Coast	Potomac River Estuary, Atlantic
Region	Virginia
Wave Climate	Medium
Municipal Type	County
Population	134,350 (2010)
Project Area	32 acres (park)

Summary – A major restoration project occurred in 1987 to control severe erosion of Aqua-Po Public Beach in Stafford County, Virginia. The project included 20,000 cubic yards of beach nourishment and four 100 foot long detached breakwaters (*see* image). It is one of the earliest beach projects in the United States to use parallel near shore breakwaters and a headland beach approach to protect against erosion. In the 1800s the point was the location of a railroad and steamboat line. A groyne field was built in the 1960s to prevent erosion, but erosion continued above the groynes, leaving the groynes 100 feet offshore.

The nearshore breakwaters have faced hurricanes and storms fulfilling their intended purpose with minimal need for maintenance. The small "sheltered-shores" restored beach is an important part of the community. This is a very successful example of using a nearshore breakwater.[2]



NEARSHORE BREAKWATER EXAMPLE, AQUIA LANDING POINT. (IMAGE SOURCE: STAFFORD PARKS[3])

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[1] Google Earth. (n.d.). Image of Pointe Sapin, New Brunswick. [image]. Retrieved from https://www.google.com/earth/

[2] Hardaway, Jr., C.S., Milligan, D.A., Wilcox, C.A., Meneghini, L.M., Thomas, G.R., Comer, T.R. (2005). The Chesapeake Bay Breakwater Database Project: Hurricane Isabel Impacts to Four Breakwater Systems. Technical Report to the U.S Army Corps of Engineers. Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia

[3] Stafford Parks. (1995). *Aquia Landing Point*. [image]. Retrieved from http://web.vims.edu/physical/research/shoreline/docs/Summaries/Aqua-Po_Summary.pdf

4.8 Retaining Wall

Coastal risk		Adaptive response			
Erosion	Flooding	Retreat	Accommodate	Protect	
				Hard structure	Soft approach

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 tools (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.

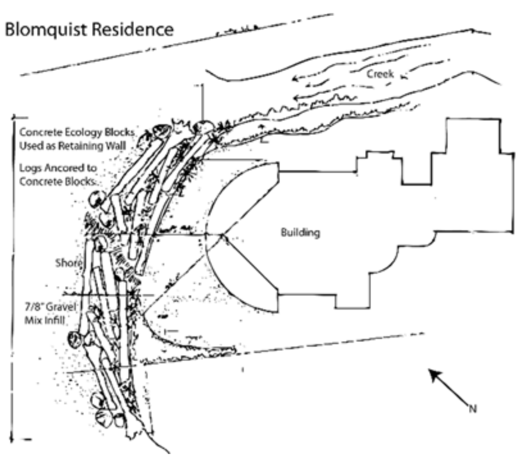
Retaining walls made of wire-mesh baskets or 'gabions' (left) and timber (right). (Image Source: Prince Edward Island Government[1])

OPPORTUNITIES	CONSTRAINTS
• 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.	• 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.

Retaining Wall Example (International)

Blomquist Beach, Natural Mimicking Bulkhead near Poulsbo, Washington

Profile	
Coast	Hood Canal, Puget Sound
Region	Washington State
Wave Climate	Medium to Low
Municipal Type	City
Population	9200 (2010)
Project Area	28.7 m (cliff width)
Year	Private landowner $15,500 USD ($50.60/m)



Soft shoreline protection on residential property on Puget Sound, Washington. (Image Source: Zelo, et al., 2000[2])

Summary – The area where this property is located (Blomquist Beach, near Poulsbo, Washington) has a bluff with a short foreshore beach. A creek empties nearby and contributes to erosion. Hood Canal is a natural fjord connected to Puget Sound. Extreme high tides in the area can be as high as 4.3 metres with a mean high tide of 3.3 metres. The project involved filling the beach with a 7/8" gravel mix and anchored logs attached to cement ecology blocks (concrete block with a groove in the bottom face and a tongue on the top face to allow stacking without slippage. They can be readily dismantled and reused). The use of large ecology blocks on this site was possible because there was an access route for heavy machinery. The blocks allow the larger logs to be anchored with just two cables.[3]

Context – Neighbouring properties on both sides of the site are heavily armored and the beaches in front of these houses are significantly damaged by scour (underwater erosion). A rip-rap bulkhead to the north reflects wave energy off of it and onto Blomquist Beach. In 1996, approximately 10 feet of beach and backshore was lost during storms. The Department of Fish & Wildlife has restricted the constructions of standard rock bulkheads. The Department did permit the more natural beach and bluff construction at this site.[4]

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1 PEI Government. (n.d.). *Retaining walls*. [image]. http://www.gov.pe.ca/photos/original/eff_shorerosion.pdf

2 Ibid.

3 Zelo, I., Shipman, H., & Brennan, J. (2000). *Alternative Bank Protection Methods for Puget Sound Shorelines*, Shorelander and Environmental Assistance Program. Publication #00-06-012, Washington, Department of Ecology, Olympia, WA. Retrieved from http://www.ellisportengineering.com/images/WDOE_alt_shoreline_protection.pdf

4 Ibid.

4.9 Near Shore Artificial Reefs

Coastal risk		Adaptive response			
Erosion	Flooding	Retreat	Accommodate	Protect	
				Hard structure	Soft approach

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.[1]

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.[2]

Concrete reef balls. (Image Source: Paul Stern, The CT Mirror[3])

OPPORTUNITIES	CONSTRAINTS
• Relatively cost effective. • Adds to the environmental sustainability of the shoreline. • Can be used as part of a Living Shoreline. • Will naturally increase in height as sea- level rises over long periods of time.	• 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.

Artificial Reef Example (International)

Stratford Point Saltmarsh Restoration

Profile	
Coast	Long Island Sound
Region	Connecticut
Wave Climate	Medium to High
Municipal Type	County
Population	51,384 (2010)
Project Area	3.5 acres
Year	US Fish and Wildlife Service ($1,296,000 USD); Long Island Sound Funders Collaborative ($59,000 USD); Sacred Heart University ($80,000 USD)

Summary – 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 60-foot 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.[4]

Context – 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. Site work began May 1, 2014. Construction and installation took little time; however, restoration of the saltmarsh and growth of oyster reefs will take a number of years.[5,6]

Reef ball installation. (Image Source: Brian A. Pounds, Connecticut Post[7])

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[1] 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

[2] 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

[3] Paul Stern, The CT Mirror. (2014). Concrete reef balls. [image]. Retrieved from http://ctmirror.org/2014/05/14/success-not-guaranteed-for-unique-stratford-reef-project/

[4] Doresy, M. (2014). Students Apply Principles of Green Technology to Artificial Reefs. Retrieved from http://www.valdosta.edu/about/news/releases/2014/05/students-apply-principles-of-green-technology-to-artificial-reefs-.php

[5] Beekey, M. (2013). SHU and CT Audubon Receive Grant to Implement Coastal Protection Project at Stratford Point", Sacred Heart University News Story Oct. 2013. Available at: http://works.bepress.com/mark_beekey/9

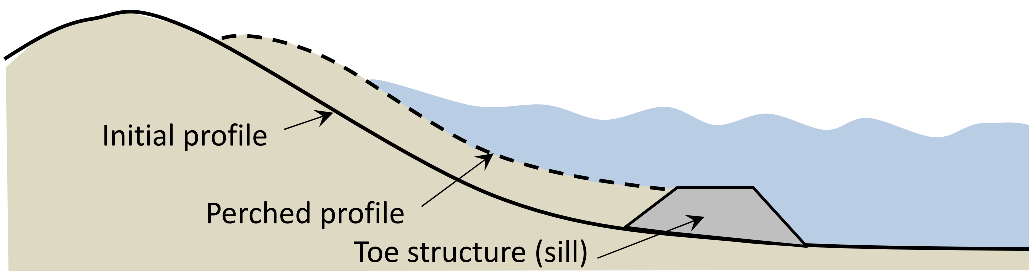
[6] Burgeson. (2014). Reef Balls: Latest try at restoring marsh. Connecticut Post, Published 5:30 pm, Tuesday, May 6, 2014

[7] Brian A. Pounds, Connecticut Post. (2014). Reef ball installation. [image]. Retrieved from http://www.ctpost.com/printpromotion/article/Reef-Balls-may-stop-erosion-5458055.php

4.10 Perched Beach (Sill)

Coastal risk		Adaptive response			
Erosion	Flooding	Retreat	Accommodate	Protect	
				Hard structure	Soft approach

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.



(Image Source: Vincent Leys, CBCL Limited)

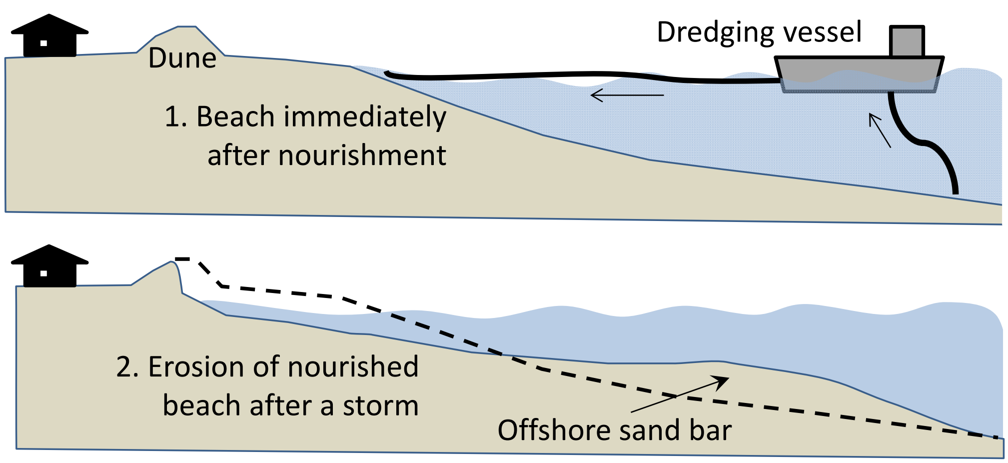
OPPORTUNITIES	CONSTRAINTS
• Reduces the amount of sand required for beach nourishment. • Decreases the maintenance costs for seawalls. • Creates beach areas for recreation and natural habitat on coasts with steep profiles.	• Initial costs of installing a sill can be high. • Loss of sand over the sill during extreme storms is irreversible. • Not suitable for coasts with waves impacting 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. • Will still require beach nourishment on a coast with small quantities of available sediment.

4.11 Beach Nourishment

Coastal risk		Adaptive response			
Erosion	Flooding	Retreat	Accommodate	Protect	
				Hard structure	Soft approach

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 adds sediment 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.



(Image Source: Vincent Leys, CBCL Limited)

OPPORTUNITIES	CONSTRAINTS
• 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.	• Reliable sources of good quality sand required. • Does not reduce the amount of erosion that occurs naturally. • Requires regular and expensive maintenance. • Regulatory requirements.

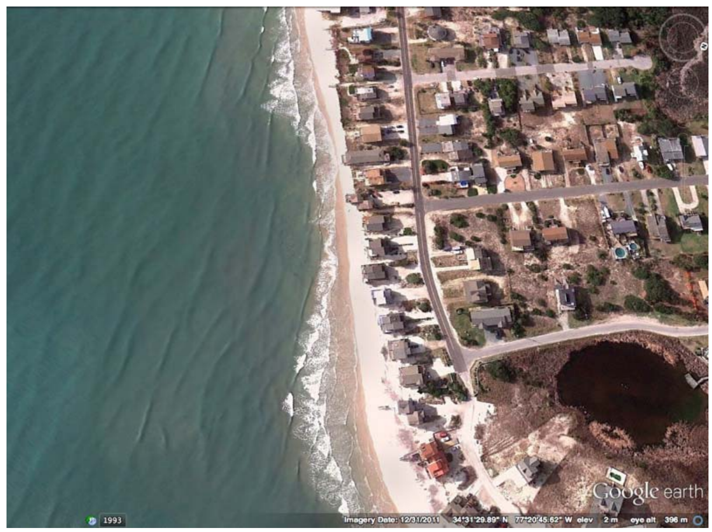
Beach Nourishment Example (International)

Dredging and Beach Nourishment, North Topsail Beach, North Carolina

Profile	
Coast	Atlantic
Region	North Carolina
Wave Climate	High
Municipal Type	Town
Population	955 (2010)
Project Area	2.4 km (restored beach)
Funding/Costs	$5.6 million USD 100% town funded through existing beach fund and special obligation bonds

Summary – 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 kilometres 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.[1]

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.[2]



Before and after beach nourishment at Topsail Beach, NC. (Image Source: Google Earth[3])

[1] 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

[2] Faulkner, C. (2013). Town of North Topsail Beach Press Release – New River Inlet Channel Realignment Project - 2/7/2013

[3] Google Earth. (2011). Image of North topsail Beach, North Carolina. [image]. Retrieved from https://www.google.com/earth/

4.12 Plant or Bio-Engineered Stabilization

Coastal risk		Adaptive response			
Erosion	Flooding	Retreat	Accommodate	Protect	
				Hard structure	Soft approach

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 water logged 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).

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 the site conditions. (Image Source: ESANS[1])

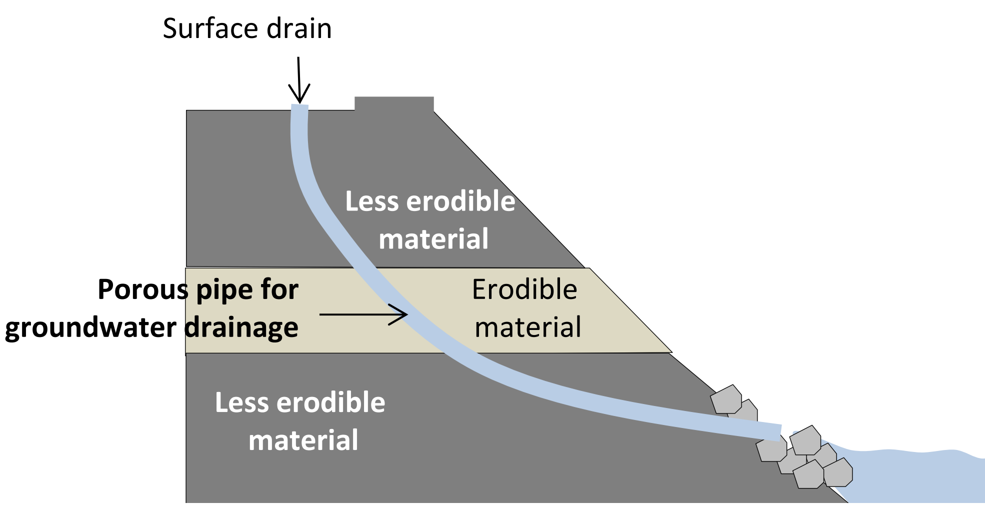
OPPORTUNITIES	CONSTRAINTS
• Cost effective solution. • Positive environmental solution for erosion. • Helps build dunes and stabilize bluffs, cliffs and salt marshes. • Aquatic plants can reduce wave energy and will naturally respond to sea level rise. • Once planted, it will require very little maintenance and will often regrow after extreme events.	• 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.

[1] ESANS. (n.d.). Environmental Services Association Nova Scotia. [image]. Retrieved from http://www.esans.ca/images/pdfs/ARC_spring%202014_final.pdf

4.13 Passive Bluff Drain

Coastal risk		Adaptive response		
Erosion	Flooding	Retreat	Accommodate	Protect

Passive bluff drains reduce erosion caused by water runoff on a bluff. A bluff drain involves pipes with holes along its length that allow water to seep into the pipe. This design provides a route for water to escape the soil and drain into the ocean. Passive bluff drains may be installed in bluffs through directional drilling (i.e. drill a curving hole), or along the face of the slope. Professional analysis of slope stability and drainage is required to determine if a passive bluff drain is appropriate for an area.



How a bluff drain pipe works. (Image Source: Vincent Leys, CBCL Limited)

OPPORTUNITIES	CONSTRAINTS
• Reduces bluff erosion due to overland water runoff. • Inexpensive and can extend the life of other protection tools such as scour protection or retaining walls. • Conveyance system does not place water on the slope.	• Susceptible to the impacts of erosion and will require relocation if erosion continues. • Without proper energy dissipation such as rip-rap protection at the base of the slope, the discharged water can cause erosion at the slope toe and beach. • Difficult to support and stabilize a pipe along steep eroding slopes.

Bluff Drain - International Example

Retrofit Drainage for Subdivision on Fox Island, Washington

Profile	
Coast	Puget Sound
Region	Washington State
Wave Climate	Low to Medium
Municipal Type	Census-Designated Place/Island
Population	3,633 (2010)
Project Area	10 acres (subdivision)

Summary – This project on Fox Island, Washington, involved the installation of drainage control measures including vegetated drainage ditches, stormwater retention areas, and tightlines (see photo) down to the base of the slope. These measures were put in place for erosion control along with revegetation of the site. The project also involved redesigned soil fills and re-contouring the slope and removing, reinforcing, and constructing a retaining wall.

The Problem – Subdivision development occurred in a previously undeveloped and heavily vegetated area. The development involved extensive slope clearing, grading, cuts, and fills of the land. No engineered site drainage features and few erosion control measures were incorporated into the final site design. No analysis was performed to evaluate fill placement on the steep slope and the drainage system was not effective in intercepting and routing surface water flows. Heavy site erosion and landslides were caused by inadequately dealing with permanent stormwater.

Tightlines – Tightlines are solid wall pipes which carry collected water down a steep slope gradient without exposing the slope face to soil saturation and channel erosion from inland water drainage. These drains are usually combined with some energy dissipating structure at the bottom of the pipe such as a rip-rap pad.

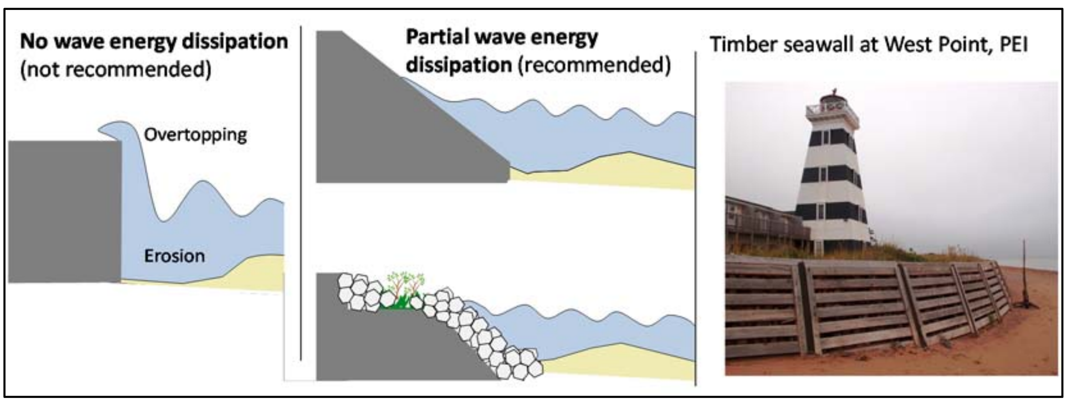
Example of tightline drainage in Washington. (Image Source: State of Washington Department of Ecology[1])

[1] State of Washington Department of Ecology. (n.d.). *Tightline drainage*. [image]. Retrieved from http://www.ecy.wa.gov.

4.14 Seawall

<table>
<tr><th colspan="2">Coastal risk</th><th colspan="4">Adaptive response</th></tr>
<tr><td rowspan="2">Erosion</td><td rowspan="2">Flooding</td><td rowspan="2">Retreat</td><td rowspan="2">Accommodate</td><td colspan="2">Protect</td></tr>
<tr><td>Hard structure</td><td>Soft approach</td></tr>
</table>

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.



Examples of seawall concepts (left and center) and local example of a seawall (right). (Image Sources: Vincent Leys, CBCL Limited)

OPPORTUNITIES	CONSTRAINTS
• Requires little space and is useful when space for other protection tools is limited. • Mitigates both flooding and erosion of a built shoreline. • Beneficial if the shoreline has valuable infrastructure or important buildings at risk.	• 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.

Seawall Example (International)

Eco-Friendly Seawall in North Turramurra, New South Wales, Australia

Profile	
Coast	Hawkesbury River Estuary, Pacific
Region	New South Wales, Australia
Wave Climate	Low
Project Area	80 m
Location (Google Earth)	Long. 151.1556 E Lat. -33.6223 S

Summary – 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.[1] 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.[2] 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.[3,4]

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.

Bobbin Head Seawall. (Image Source: D. Wiecek, Office of Environment and Heritage)

[1] 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/

[2] 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

[3] 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

[4] 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

4.15 Buried Revetment

Coastal risk		Adaptive response			
Erosion	Flooding	Retreat	Accommodate	Protect	
				Hard structure	Soft approach

A buried revetment typically describes a rock slope ('revetment') 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 sink holes 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.

Buried revetments at Dominion Beach, NS, two years after construction (top), and Lighthouse Beach, NS, six years after construction. (Image Sources: Vincent Leys, CBCL Limited)

OPPORTUNITIES	CONSTRAINTS
• 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.	• 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.

Buried Revetment Example (International)

Bay Head, Ocean County, New Jersey

Profile	
Coast	Atlantic
Region	New Jersey
Wave Climate	High
Municipal Type	Borough
Population	968 (2010)
Project Area	1.2 km (beach)

Summary – Bay Head is located on a narrow barrier spit separating Barnegat Bay from the Atlantic Ocean in New Jersey. An old 1,200 meter seawall from 1882 was covered by dunes in the foreshore. The seawall stands about 1.5 metres above the beach with dunes built up and piled on top. The dunes took the initial brunt of Hurricane Sandy in 2012 and became a source of sand through erosion; however, the old seawall prevented destruction of property in Bay Head.[1]

The dune systems in the area have been good at preventing inland erosion and flooding during normal tides and storm events. In the neighbouring area of Mantoloking, dunes alone were not effective against larger hurricane events such as Hurricane Sandy. The combination of the hard seawall and overlying soft sand dune contributed to the structure's effectiveness in Bay Head.[2]

Buried Revetment Post-Hurricane Sandy. (Image Source: Jennifer Irish[3])

[1] Irish, J.L., Lynett, P.J., Weiss, R., Smallegan, S.M., Cheng, W. (2013). Buried relic seawall mitigates Hurricane Sandy's impacts. *Coastal Engineering, 80*, 79-82

[2] Poppick, L. (2013). *How Long-Forgotten Seawall Fended Off Sandy*. Retrieved from http://www.livescience.com/38291-old-seawall-stopped-sandy.html

[3] Jennifer Irish (Virginia Tech). Image taken November 14, 2012.

4.16 Living Shorelines (Coastal Wetlands and Salt Marsh Restoration)

Coastal risk		Adaptive response			
Erosion	Flooding	Retreat	Accommodate	Protect	
				Hard structure	Soft approach

Saltmarshes 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.[1] Natural materials help provide short-term protection and, as the materials decompose, will encourage plant growth and shore stabilization. Re-establishing saltmarshes and coastal wetlands reduces the impacts of flooding and erosion and strengthens the natural ecosystem.[2,3]

Planting appropriate vegetation may be required in the process of restoring saltmarshes and coastal wetlands. If used in combination with other tools, 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).[4]

Cole Harbour, Salt Marsh Trail, NS. (Image Source: Vincent Leys, CBCL Limited)

OPPORTUNITIES	CONSTRAINTS
• 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 are capable of adapting 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.[5]	• 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 has to be done by re-vegetating the shoreline with transplanted wetland plants. • May require the acquisition of private land. This increases the upfront capital cost of restoration.

Living Shoreline (combined with nearshore breakwaters) Example (International)

Patuxent River, Asbury, Calvert Country, Maryland

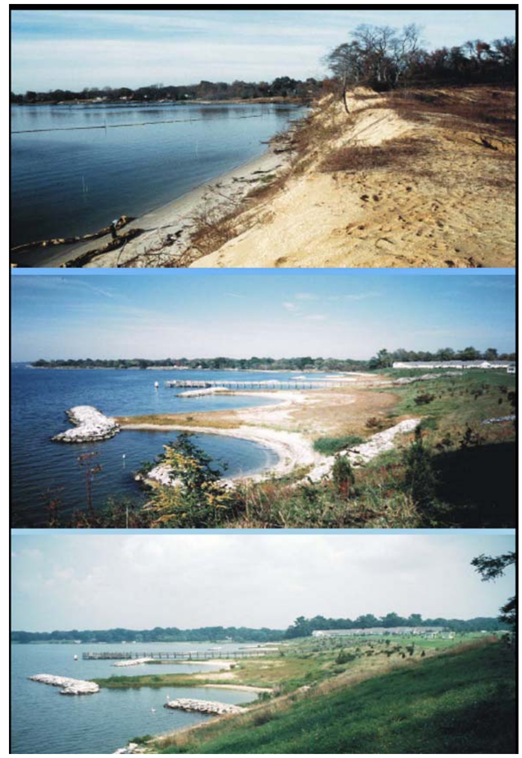
Profile	
Coast	Chesapeake Bay, Atlantic
Region	Calvert County, Maryland
Wave Climate	Exposed (wind fetch distance 10 km)
Municipal Type	Town
Project Length	1,900 feet long
Location (Google Earth)	Longitude 76.470 West Latitude 38.346 North

Summary – The town of Ashbury on the Patuxent River in Chesapeake Bay, Maryland is the site of a combined living shoreline and nearshore breakwater installation. The purpose of installing the living shoreline was to protect a 12 m (40 ft) upland bank from severe erosion, thereby allowing for safe construction of a retirement community and recreation area.[6]

The historic erosion rate of the 12 m high sand banks was 0.6 m per year, with wave action predominantly from the northwest causing alongshore sediment transport in the downdrift direction. The project used the readily available sand in the banks, which allowed for a significant cost savings.

The project is 600 m long and consists of three straight headland breakwaters, 30 m long and spaced 60 m apart, and two transitional breakwaters on the downriver (downdrift) and upriver (updrift) ends. The area is constrained by a revetment and a short spur on the downriver and upriver ends.

Wetland vegetation was planted behind each breakwater and along the backshore using 23,000 m^3 of sand (from the adjacent banks) as a base.[7]



Living shoreline combined with nearshore breakwaters before (1994) and after (1998 and 2000), Town of Ashbury, MD. (Image Source: Hardaway, n.d.[8])

[1] 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

[2] Lamont, G., Readshaw, J., Robinson, C., & St-Germain, P. (2014). Greening shorelines to enhance resilience: An evaluation of approaches for adaptation to sea level rise. Prepared by SNC-Lavalin Inc. for the Stewardship Centre for BC and submitted to Climate change Impacts and Adaptation Division, NRCan, AP040

[3] 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

[4] 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

[5] Baustian, J.J., Mendelssohn, I.A., Hester, M.W. (2012). Vegetation's importance in regulating surface elevation in a coastal salt marsh facing elevated rates of sea level rise. Global Change Biology, 18(11), 3377-3382. doi:10.1111/j.1365-2486.2012.02792.x

[6] Virginia Institute of Marine Science. Breakwater Database – Ashbury. Retrieved from http://www.vims.edu/research/departments/physical/programs/ssp/shoreline_management/breakwaters/ge_map/index.php

[7] Ibid.

[8] Hardaway, C.S. (n.d.). *Assisted living shorelines and high bank stabilization in Chesapeake Bay*. [Image]. Retrieved from http://dnr.maryland.gov/ccs/pdfs/hw/calvert/alshbscb_csh.pdf

4.17 Dune Building

Coastal risk		Adaptive response			
Erosion	Flooding	Retreat	Accommodate	Protect	
				Hard structure	Soft approach

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.

Dune restoration during the construction of a buried revetment at Basin Head, PEI. (Image Source: Jody MacLeod, CBCL Limited)

OPPORTUNITIES	CONSTRAINTS
• 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.	• 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.

DUNE BUILDING EXAMPLE (INTERNATIONAL)

Leirosa Sand Dune Rehabilitation, Figueira da Foz, Portugal

Profile	
Coast	Atlantic
Region	Portugal
Wave Climate	High
Municipal Type	Town
Population	Approx. 500
Project Area	Phase 1: 1.8 km Phase 2/3: 120 m
Funding/Costs	Phases 2 and 3 total cost $369,890 CDN; Funding was public private partnership

The Problem – The Leirosa sand dunes in Figueira da Foz, Portugal, experience strong erosion and a loss of sediment deposits due to dams and bank hardening on the Mondego River and the Figueira da Foz Port. The installation of a submarine outfall pipe in 1995 for a pulp mill led to further changes to the dune system. The use of heavy machinery and breakwater located close by aggravated the long-term problems of erosion in the coastal ecosystem.

Phase 1 (March 2000 – May 2000) – The dunes were reconstructed with traditional sand mounds, dune fences and dune grass. This treatment was not sufficient, however, as a severe storm destroyed most of the oceanic side of the rehabilitated sand dune the next winter.

Phase 2 (2005) – Layers of geotextiles (synthetic fabric) filled with sand where used to strengthen the dune structure on the ocean side in areas where dunes had collapsed. Once the sand containers were in place the barrier was covered with sand and planted with grass. High tides and storm surge in 2006 partially damaged the geotextile dune structure. Wave action lead to an opening of the geotextile containers in some parts of the dune system. This is likely because the containers were not sealed properly.[1]

Phase 3 (2008 – 2009) – Geotextile tubes were installed at the base of dunes closest to the town and more dune grass was planted.[2] Construction of an artificial offshore reef further reduced wave action.

This example illustrates how a combination of various site-specific approaches could be required for a successful outcome.

LERIOSA SAND DUNES AFTER PHASE 1 OF RESTORATION. (IMAGE SOURCE: ANTUNES DO CARMO ET AL.[3])

[1] Antunes do Carmo, J., Reis, C., Freitas, H. (2010). Working with nature by protecting sand dunes; lessons learned. Journal of Coastal Research, 26(6), 1068-1078. doi:10.2112/JCOASTRES-D-10-00022.

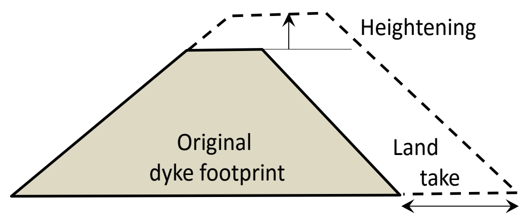
[2] Ibid.

[3] Ibid.

4.18 Dykes

Coastal risk		Adaptive response			
Erosion	Flooding	Retreat	Accommodate	Protect	
				Hard structure	Soft approach

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.



Storm impacts at Avonport dyke (left) and representation of land take implications of dyke heightening (right). (Image Sources: left – Van Proosdij[1]; right – Vincent Leys, CBCL Limited)

OPPORTUNITIES	CONSTRAINTS
• 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.[2]	• 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.

Dyke Example (International)

Dyke protecting the Lands around the Eems Dollart (Eems River Estuary Bay)

Profile	
Coast	Eems River Estuary, North Sea
Region	Netherlands
Wave Climate	Medium
Municipal Type	Towns
Population	Termunten: 420 (2008) Woldendorp: 1000 (2008) Bad Nieuweschans: 1,510 (2004)
Coast	Eems River Estuary, North Sea

Summary – The area around the Eems 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 have been 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.

Broad Green Dykes – The cost per kilometre of a broad green dike 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.

View of protected land from the Eems Dollart Dyke. (Image Source: Alterra Eems Dollart Report[3])

[1] 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

[2] Brampton, A.H. (1992) Engineering significance of British saltmarshes in Allen, J.R.L., Pye, K. (Eds.). Saltmarshes: Morphodynamics, conservation and engineering significance. (pp. 115-122). Cambridge: Cambridge University Press.

[3] van Loon-Steensma, J.M van (ed.), Schelfhout, H.A., Broekmeyer, M.E.A., Paulissen, M.P.C.P., Oostenbrink, W.T., Smit en, C., Cornelius, E-J. (2014). Nadere verkenning Groene Dollard Dijk; Eencivieltechnische, juridische en maatschappelijke verkenning naar de haalbaarheid van een bredegroene dijk en mogelijke kleiwinning uit de kwelders. Wageningen, Alterra Wageningen UR (University & Research centre), Alterra-rapport 2522. 90 blz.; 32 fig.; 23 tab.; 56 ref

4.19 Tide Barriers/Aboiteaux

Coastal risk		Adaptive response			
Erosion	Flooding	Retreat	Accommodate	Protect	
				Hard structure	Soft approach

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.

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Aboiteau in Great Village, Nova Scotia. (Image Source : Vincent Leys, CBCL Limited)

OPPORTUNITIES	CONSTRAINTS
• 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.	• 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.

Tidal Barriers Example (Regional)

La Planche River Aboiteau, Bay of Fundy, Amherst NS

Profile	
Coast	Bay of Fundy, Atlantic
Region	Amherst, NS
Owner	NS Department of Agriculture
Watershed Area	13,263 ha
Location (Google Earth)	Long. 64.254 W Lat. 45.830 N

Summary – 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. The values are based on the assumption that the extreme storm surge may coincide with high tide and are therefore conservative. Based on costs vs. benefits, the design crest elevation was selected to accommodate the expected 1-in-100 year storm surge level in year 2055 (also close to the 1-in-10 year storm in 2085). An extra allowance was added to accommodate for 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.

La Planche River Aboiteau near completion, August, 2015. (Image Source: Suvir Pursnani, CBCL Limited)

4.20 DREDGING

Coastal risk		Adaptive response		
Erosion	Flooding	Retreat	Accommodate	Protect

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.

EXAMPLE OF A DREDGING PROJECT FROM A SMALL-SCALE CHANNEL MECHANICAL EXCAVATION IN SALMON RIVER, NOVA SCOTIA. (IMAGE SOURCE: GRAEME MATHESON, SAINT MARY'S UNIVERSITY)

OPPORTUNITIES	CONSTRAINTS
• 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 engineering interventions such as beach nourishment or dyke maintenance.	• 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 is if there is a regular natural supply of sediment. • Disrupts the natural equilibrium between erosion and deposition.

Dredging - International Example

Dredging for Tidal Openings, Gosnold, Cape Cod, Massachusetts

Profile	
Coast	Buzzards Bay, Atlantic
Region	Massachusetts
Wave Climate	Low to Medium
Municipal Type	Town
Population	75 (2010)
Project Area	35 km2 (Island)

View of Gosnold highlighting the Western Pond (Image Source: Google Earth[1])

Summary – The town of Gosnold is in the Cape Cod and Islands region of Massachusetts. The purpose of dredging in the area is to create tidal openings to Buzzards Bay. Dredging reintroduces tidal flows into the Western and Central Ponds and protects the fresh water pond. The town is attempting to re-establish the opening and dredge it annually, or as needed, to maintain the connection. The excavated material is placed on nearby upland areas above the high tide line. This is part of a larger county-wide initiative to provide beach nourishment, dredging, and structural reconfiguration of inlets and inlet protections. These improve natural defenses and circulation in order to minimize storm impacts.[2]

The connection between Buzzards Bay and Western Pond is 20 feet wide and 170 feet long. The connection between Western Pond and Central Pond is 237 feet long and 20 feet wide. Both will be excavated to the mean low water level.[3]

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[1] Google Earth. (n.d.). Image of Gosnold, Massachusetts. [image]. Retrieved from https://www.google.com/earth/

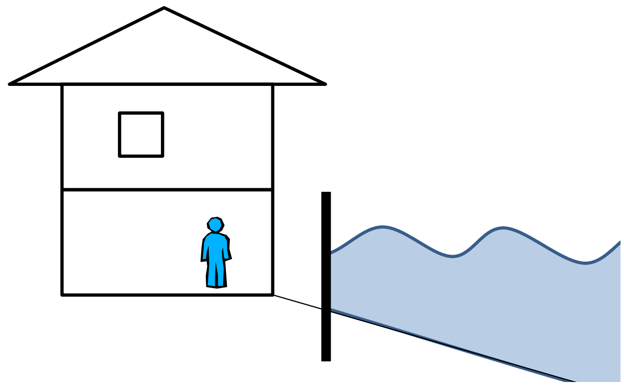
[2] State of Massachussetts. (2014). StormSmart Properties Comparison Chart - Relative Costs of Shoreline Stabilization Options. Retrieved from http://www.mass.gov/eea/agencies/czm/program-areas/stormsmart-coasts/stormsmart-properties/

[3] U.S. Army Corps of Engineers. (2014). Reducing Coastal Risks on the East and Gulf Coasts. Committee on USACE Water Resources Science, Engineering, and Planning – National Research Council.

4.21 Floodwalls/Dry Flood Proofing

Coastal risk		Adaptive response			
Erosion	Flooding	Retreat	Accommodate	Protect	
				Hard structure	Soft approach

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.[1,2,3]



Schematic diagram showing dry flood proofing. (Image Source: Vincent Leys, CBCL Limited)

OPPORTUNITIES	CONSTRAINTS
• 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.	• 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.

Dry Flood Proofing Example (International)

State of Maine towns, Mandatory Structure Flood Proofing

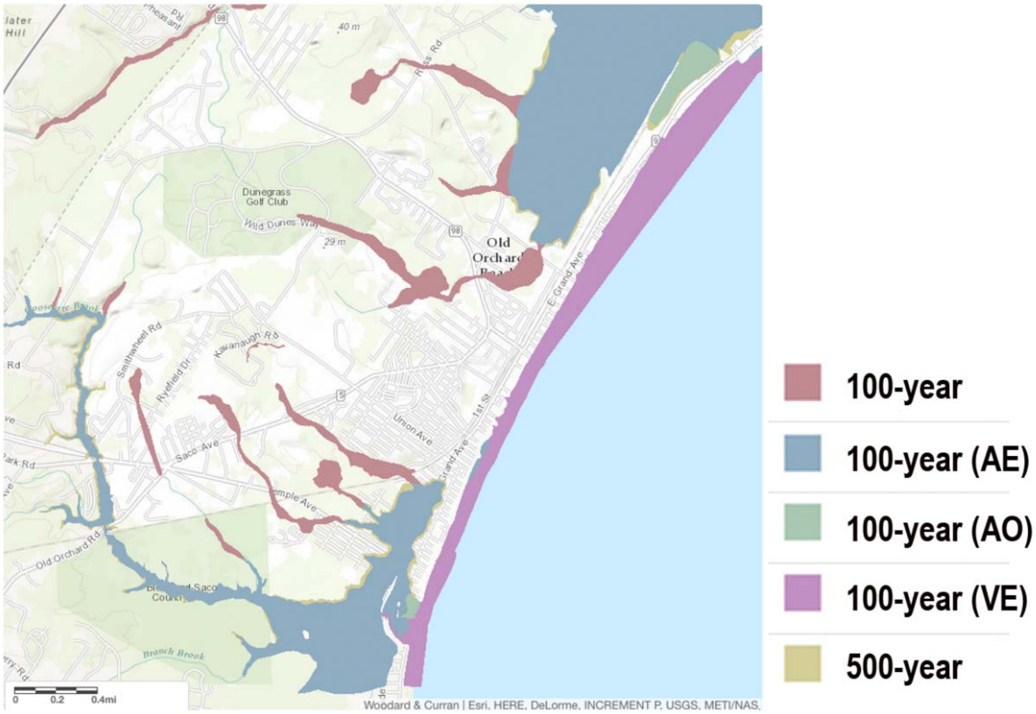
Profile	
Coast	Gulf of Maine, Atlantic
Region	Maine
Wave Climate	Medium to High
Municipal Type	Town/Census Designated Place
Population	12,529 York / 2,568 York Beach (2010)
Project Area	142 km^2 (town)

Summary – 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)[4] 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 selected size flood and floodway conditions."[5] In practical terms for structures this means the elevation of the first floor 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.[6] The town of York goes further and requires two feet of freeboard.[7] 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.[8] It also means an expansion of the area where the flood management ordinance will apply.

Example of a removable floodwall/gate in Maine. (Image Source: Flood Control America[9])



PROPOSED EXPANDED 100-YEAR FLOOD ZONES FOR TOWN OF OLD ORCHARD BEACH. (IMAGE SOURCE: CREATED BY PENELOPE KUHN WITH AN ONLINE MAPPING TOOL FROM WOODARD & CURRAN, ESRI[10])

Context – 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 recently 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.

[1] FEMA (Federal Emergency Management Agency). (2010). Wet Floodproofing. Washington DC: US Dept. of Homeland Security.

[2] Southern Tier Central Regional Planning & Development Board (STC-RPDB). (2010).

[3] 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

[4] 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?nodeld=PTIICOOR_CH70FLARTIIFLMAOR

[5] 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

[6] 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?nodeld=PTIICOOR_CH70FLARTIIFLMAOR

[7] 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

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

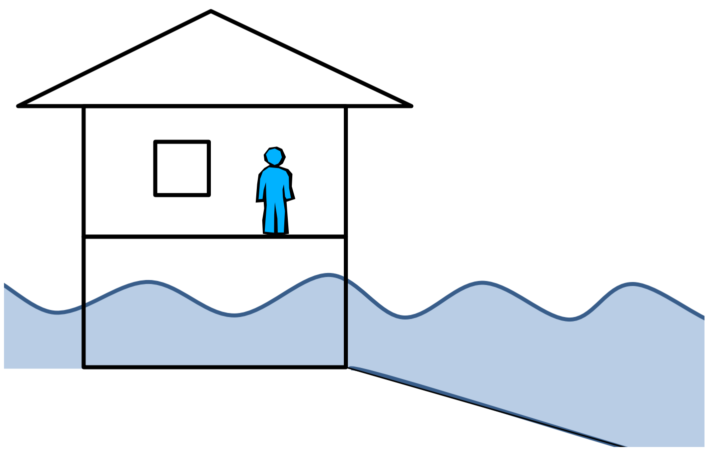
[9] Flood Control America. (n.d.). Example of removable floodwall. [image]. Retrieved from http://floodcontrolam.com/flood-wall-applications/flood-proofing/

[10] 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

4.22 Wet Flood Proofing Buildings

Coastal risk		Adaptive response		
Erosion	Flooding	Retreat	Accommodate	Protect

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.[1,2,3]



Schematic diagram showing wet flood proofing, lower levels 'permit' flooding.
(Image Source: Vincent Leys, CBCL Limited)

OPPORTUNITIES	CONSTRAINTS
• Suitable for most coastal types. • Allows for certain uses such as parking in areas that would otherwise be unsuitable for development.[4] • 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.[5]	• 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.

Wet Flood Proofing Example (International)

Changing Development Regulations to Allow Wet Flood Proofing in Sea Bright, New Jersey

Profile	
Coast	Atlantic
Region	New Jersey
Wave Climate	Medium to High
Municipal Type	Borough
Population	1,412 (2010)
Project Area	1.9 km^2 (borough)

Example of a flood vent. (Image Source: Smart Vent Products, Inc.)

Impact on this flood-proofed housing is minimal despite major impacts to Sea Bright shoreline infrastructure as indicated by the beached sail boat. (Image Source: Star-Ledger[6])

Summary – Sea Bright, New Jersey is using multiple structural retrofit 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.

[1] 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 - 1

[2] Southern Tier Central Regional Planning & Development Board (STC-RPDB), 2010

[3] 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

[4] FEMA (Federal Emergency Management Agency). (2010). *Wet Floodproofing*. Washington DC: US Dept. of Homeland Security.

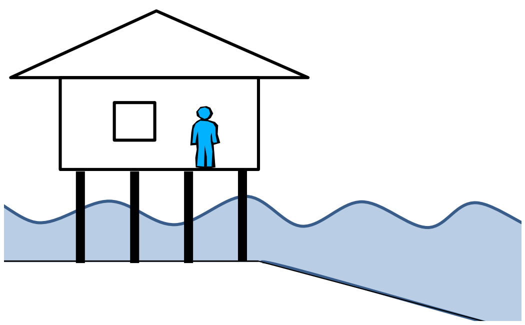
[5] FEMA (Federal Emergency Management Agency). (2007). *Selecting Appropriate Mitigation Measures for Floodprone Structures.* Washington DC: US Department of Homeland Security. Retrieved from www.fema.gov/library/viewRecord.do?id=2737

[6] Star-Ledger. (n.d.). *Flood-proofed housing*. [image]. Retrieved from http://media.nj.com/star-ledger/photo/2012/11/-c1b27acd1cb3c629.jpg

4.23 Raised Infrastructure

Coastal risk		Adaptive response		
Erosion	Flooding	Retreat	Accommodate	Protect

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.



Schematic showing wet flood proofing (Image Source: Vincent Leys, CBCL Limited) Raised house in Slidell, Louisiana (Image Source: Deltec Homes[1])

OPPORTUNITIES	CONSTRAINTS
• 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.[2]	• 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.

Raised Building Example (International)

Prioritizing Residential Elevation in Waveland, Mississippi

Profile	
Coast	Gulf of Mexico
Region	Mississippi
Wave Climate	Medium
Municipal Type	City
Population	2253 (2010)
Project Area	589 m (Bridge)
Funding/Costs	$69,000 to $89,000 USD range for a 1000+ sq ft house

Summary – By 2013, residential elevation was a new high priority action in Waveland, Mississippi, featuring in the *Local Hazard Mitigation Plan for the City of Waveland*. New building code guidelines have been adopted and most construction companies in the area specialize in raised buildings with stilts, breakaway lower portions (portions that do not provide structural support to the building), and piling (deep column) foundations. All new homes are being constructed above the Hurricane Katrina flood levels and many existing buildings are being elevated. The City has developed educational materials to inform citizens of their risk to flooding and recommends ways they can protect themselves and their property from floods. Recommendations include raising buildings.[3]

Hurricane Katrina – The city of Waveland was ground zero for Hurricane Katrina in 2005 and was hit harder than any other community on the Gulf Coast. The storm surge was nearly 8 metres and heavily flooded the town (the entire municipality is less than 5 metres above sea level). The surge destroyed or damaged approximately 90% of residences as well as 100% of the businesses.

Raising Options – When a house needs to be elevated, a treated wood pile (deep column) foundation is faster and cheaper to build than a concrete slab placed on fill dirt that has to be compacted. Additionally, homeowners can use the space underneath the house for parking, storage or patio space. However, the structure in general is more susceptible to damage from debris and scouring during flood events.[4]

Example of a raised house in Waveland, Mississippi. (Image Source: Thornhill Construction[5])

[1] Deltech Homes. (n.d.). Raised house. [image]. Retrieved from http://www.deltechomes.com/galleries/photo-gallery/hurricane-resistant/

[2] 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

[3] AMEC. (2013). City of Waveland Local Hazard Mitigation Plan. Retrieved from http://www.waveland ms.gov/images/City%20of%20Waveland%20LHMP%20Update%20Complete.pdf

[4] Russell, P. (2011). Raised Wood Floor Case Study: Driving posts is much more cost effective than bringing in fill dirt. Retrieved from http://www.apawood.org/level_b.cfm?content=app_rfl_cs_bayhomes

[5] Thornhill Construction. (n.d.). Raised house. [image]. Retrieved from http://thornhill-construction.com/custom-home-builder-finishes-waveland-mississippi-home/

4.24 Floating Building/Amphibious Foundation

Coastal risk		Adaptive response		
Erosion	Flooding	Retreat	Accommodate	Protect

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.

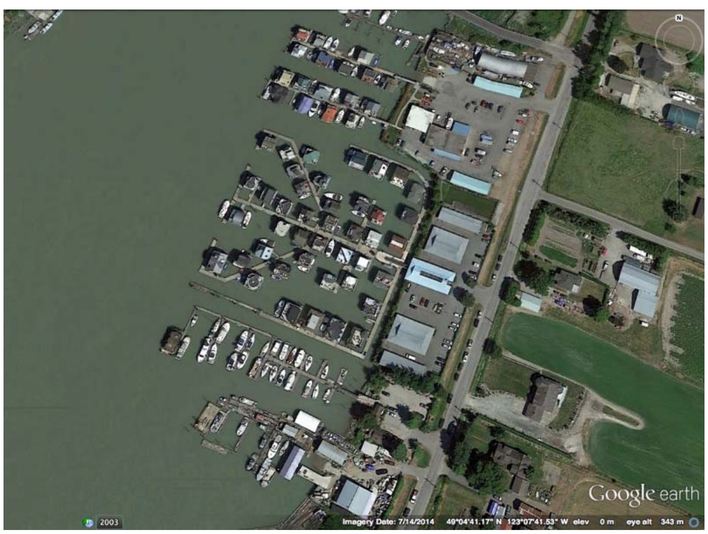
Home on an amphibious foundation in Holland. (Image Source: Dura Vermeer)

OPPORTUNITIES	CONSTRAINTS
• 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.	• 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).

Floating Building - International Example

Canoe Pass Floating Village, Ladner, British Columbia

Profile	
Coast	Fraser River Estuary, Georgia Straight
Region	British Columbia
Wave Climate	Low
Municipal Type	Village
Population	97 (estimate based on a 2.25 occupancy of 43 strata units) Ladner: 21,112 (2011 Census)
Funding/Costs	$500,000 - $800,000 CDN per home



Aerial view of Canoe Pass Floating Village, British Columbia. (Image Source: Google Earth[1])

Summary – 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 saltmarsh 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.

Ownership – 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.

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

4.25 Stormwater Management – Reduce Runoff

Coastal risk		Adaptive response		
Erosion	Flooding	Retreat	Accommodate	Protect

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 predevelopment 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, and
- vegetative filter strips.

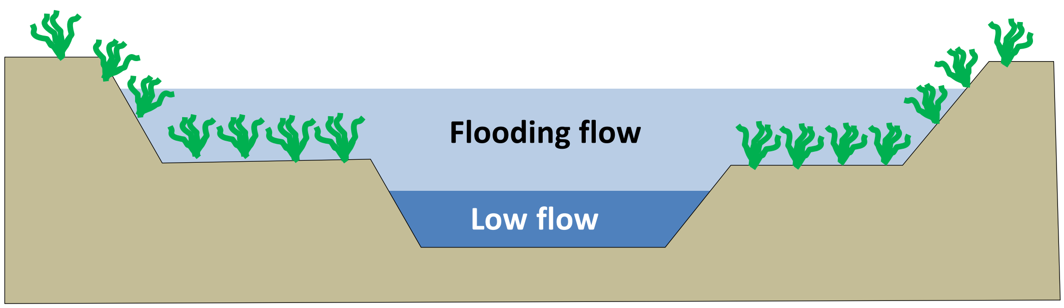
Grass swale in Yarmouth, Nova Scotia. (Image Source: Alexander Wilson, CBCL Limited)

OPPORTUNITIES	CONSTRAINTS
• 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.	• 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.

4.26 Stormwater Management – Increase Conveyance (Drainage Ditch)

Coastal risk		Adaptive response		
Erosion	Flooding	Retreat	Accommodate	Protect

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 storm water). 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.



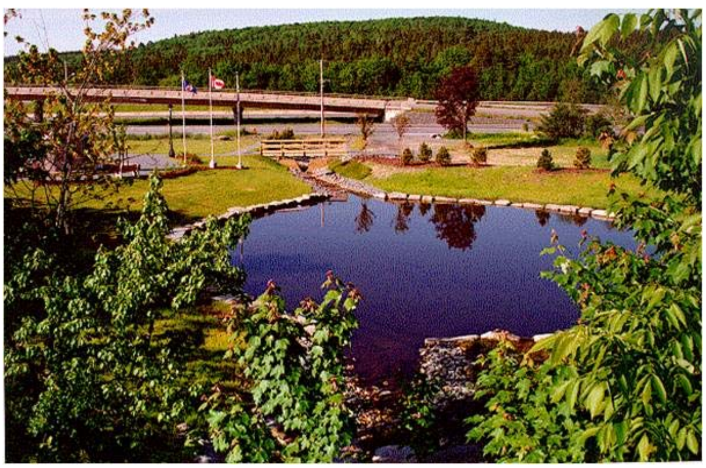
Example of two-stage drainage ditch with extra conveyance for flood events. (Image Source: Vincent Leys, CBCL Limited)

OPPORTUNITIES	CONSTRAINTS
• Provides drainage areas for flooding. • 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.	• 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.

4.27 Stormwater Management – Increase Storage (Detainment Pond)

Coastal risk		Adaptive response		
Erosion	Flooding	Retreat	Accommodate	Protect

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 contaminates.



Cenotaph Pond, Sackville NS. (Image Source: Mike DeLay, CBCL Limited)

OPPORTUNITIES	CONSTRAINTS
• 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.	• Must be located above sea level. • Volume of flood water that the ponds can deal with is restricted. • Requires a large area of land.

Stormwater Management Example (International)

Oxford, Maryland Stormwater and Flood Management Infrastructure

Profile	
Coast	Chesapeake Bay, Atlantic
Region	Maryland
Wave Climate	Medium
Municipal Type	Town
Population	641 (2012 Census)
Project Area	215 ha (town area)
Funding/Costs	A Stormwater Management and Shoreline Protection Fund was implemented with a property tax increase of $0.03 leading to ~ $100,000 USD per year.

Summary – The town of Oxford is in the process of installing flood management infrastructure including ditches, swales, culverts, drains, outfalls, and storage areas. This is in addition to a planned living shoreline initiative.[1]

A preliminary study found that stormwater infrastructure and shoreline management are inseparable and must be used together as part of a unified solution. Stormwater infrastructure is used to store and convey rainfall or tidewaters. Shoreline management addresses the reality of sea level rise.[2,3]

Context – The highest point in the town is only 11 feet above sea level and many areas fall between 4–10 feet above sea level. The majority of Oxford is located in a floodplain and low-lying land is exposed frequently to flooding. Flooding is caused by tidal and rain events and many areas of town are affected. The primary recommendation from a preliminary study was to adopt a local stormwater and shoreline protection fee. The fee will raise the revenue necessary to invest in water management infrastructure such as detainment ponds and stormwater pumps. Oxford's new fund can be applied to projects addressing coastal flood risks from tidal events, storm surges, and climate-induced sea level rise through shoreline protection.[4,5]

Example of a high power pump (left) and natural drainage (right) from the Oxford stormwater management proposal. (Image Source: Cotten Engineering, Seaford, Delaware)

[1] Edwards, R., Marin, A., Walker, E., Britt, N., Mendoza, A., Wierengo, T., Chanse, V. (2013). Design and Planning in the Face of Sea Level Change and Stormwater Issues on Maryland's Eastern Shore: Approaches to Social and Economic Resiliency & Environmental Stewardship in Oxford, Maryland. Retrieved from http://efc.umd.edu/assets/stormwater_projects/larc748_selected_projects_sustainable_growth_challenge.pdf

[2] Commissioners of Oxford. (March 31, 2014). Board Letter to the Citizens of the Town of Oxford. Retrieved from http://www.oxfordmd.net/documents2014/2nd%20Stormwater%20Letter%20to%20Citizens%20Mar%202014.pdf

[3] Town of Oxford. (2013). Oxford Stormwater and Flood Management: Findings and Options for the Future (September 24). Retrieved from http://www.oxfordmd.net/documents/Oxford_stormwater_sept_2013_FINAL.PDF

[4] Environmental Finance Centre. (2014). Oxford: Project Summary. Retrieved from http://efc.umd.edu/oxford

[5] Williamson, S. (2014). When Stormwater is Compounded by Climate Change: A Resilient Funding Mechanism in Oxford, Maryland. Retrieved from http://www.midatlanticwc.com/wp-content/uploads/2014/07/When-Stormwater-is-Compounded-by-Climate-Change.pdf

4.28 Stormwater Management – Rain Garden/Constructed Wetland

Coastal risk		Adaptive response		
Erosion	Flooding	Retreat	Accommodate	Protect

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 down spouts 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.[1] 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.

Rain garden in Sackville, NB (Image Source: Marlin 2013[2])

OPPORTUNITIES	CONSTRAINTS
• 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.	• Relatively small scale solution. • Multiple rain gardens are recommended.

Stormwater Management – Rain Garden/Constructed Wetland Example

Rain Garden (Bio-filtration zone) in Debert, Nova Scotia

Profile	
Coast	Bay of Fundy
Region	Atlantic Canada
Wave Climate	N/A
Municipal Type	District
Population	37,818 (2013)
Project Area	N/A

Summary – 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[3]. 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.

Bio-infiltration zone installation at Debert Industrial Park, Debert, NS (Image Source: Tracey MacKenzie)

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

[2] Ibid.

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

4.29 Relocate or Abandon Infrastructure (Retreat Strategy)

Coastal risk		Adaptive response		
Erosion	Flooding	Retreat	Accommodate	Protect

The decision to relocate or abandon 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 or abandon 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.

North Rustico, PEI, 21 December, 2010. (Image Source: Don Jardine, University of Prince Edward Island)

Relocation Example North Rustico (PEI) Wastewater Treatment Plant (WWTP) – 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 to 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.

OPPORTUNITIES	CONSTRAINTS
• Long-term sustainability for at-risk areas. • Lower maintenance costs. • Opportunity to build more resilient and upgraded infrastructure.	• Capital costs for relocation are high. • Potential land ownership and socio-economic challenges. • Potential community perceptions of 'abandonment'.

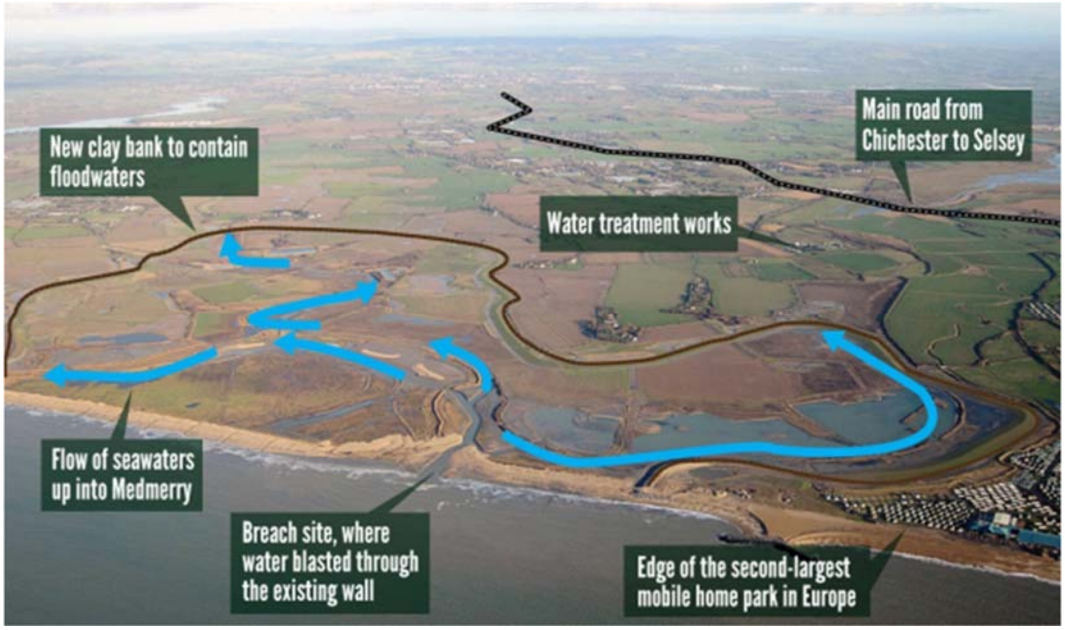
MANAGED RETREAT OF AGRICULTURAL LAND EXAMPLE (INTERNATIONAL)

Medmerry Coastal Realignment, Selsey, West Sussex, England

Profile	
Coast	Atlantic
Region	England
Wave Climate	Medium to High
Municipal Type	Town/Civil Parish
Population	9875 (2001)
Project Area	500 hectares
Funding/Costs	$46.5 million USD from UK Environmental Agency for coastal defence and habitat restoration

Summary – Medmerry is the location of a massive coastal re-alignment project carried out by the United Kingdom's Environment Agency between 2011 and 2013. The flat land of the Manhood Peninsula, where Medmerry is located, juts out into the English Channel and is exposed to flooding. The seawall and shingle bank that were protecting the coastline from flooding were costing an average of $332,000 USD per year to maintain costs. In 2008, the wall was breached leading to over $8.3 million USD in damage. There is archeological evidence that the low land was dominated by saltmarsh hundreds of years ago so the UK Environmental Agency in co-operation with the town of Selsey decided to abandon the land, used mostly as grazing pastures, and allow it to revert to tidal marsh. The retreat involved breaching the failing seawall, cutting a 100 metre channel to let the ocean reclaim 500 hectares of land and constructing a seven kilometer curved clay embankment behind the newly created inter-tidal zone. The new embankment protects the communities behind it. The realignment creates a powerful buffer zone of marsh that can absorb storm energy and provide long-term protection against sea level rise. It also creates new salt marsh habitat.[1,2]

Balancing the Cost – The project was expensive to implement in part because of the cost of acquiring the land. The results have been positive with decreased overland flooding and coastal erosion as well as the added benefits of increased tourism and bird and wildlife habitat. Initial public opposition has turned to support. The project will require little to no maintenance and the payback period will be 50 years or less. This solution was cost effective compared to the previous seawall that required annual maintenance.[3,4]



REALIGNMENT OF THE SELSEY COAST. (IMAGE SOURCE: FOSTER[5])

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[3] Ibid.

[4] Government of the United Kingdom, 2012. Policy paper: Medmerry coastal flood defence scheme. Retrieved from https://www.gov.uk/government/publications/medmerry-coastal-flood-defence-scheme/medmerry-coastal-flood-defence-scheme

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