Coastal Adaptation Toolkit

Adapting to Climate Change in Coastal Communities of Atlantic Canada

Part 1 Guidance for Selecting Adaptation Options

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Disclaimer

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

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PART 1 Guidance for Selecting Adaptation Options

Foreword

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

Adapting to Climate Change in Coastal Communities of the Atlantic Provinces, Canada: Land Use Planning and Engineering and Natural Approaches provides guidance on strategies and tools to manage climate change-driven sea level rise and coastal flooding and erosion. This set of three guidance documents supports the CLIMAtlantic web-based Coastal Adaptation Tool (https://climatlantic.ca/coastal-adaptation/). Combined, these resources help decision-makers 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 CLIMAtlantic web-based Coastal Adaptation Tool. The document also includes overviews of the land planning and management frameworks and legislation that could support coastal climate change adaptation in each of the four Atlantic Provinces and First Nations.

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

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Preface

The *Coastal Adaptation Toolkit, Adapting to Climate Change in Coastal Communities of Atlantic Canada, Part 1 Guidance for Selecting Adaptation Options*, provides foundation information that coastal communities need to select adaptation options best suited to their coastal setting and climate change impact challenges.

Part 1 is organized in five sections:

Chapter 1. Coastal Processes introduces key terms and foundation information on coastal processes, including water levels and waves and the erosion, transport, and deposition of sediment. This section also addresses climate change and coastal processes and identifies the main climate change impact concerns for the coastal regions of the Atlantic Provinces.

Chapter 2. Climate Change and Coastal Hazards presents an overview of climate change and the coastal risks and vulnerabilities in the Atlantic region.

Chapter 3. Adaptation Strategies describes what adaptation is and why it is needed. The section presents four main adaptation strategies ─ Avoid, Retreat, Accommodate and Protect ─ and local examples of each strategy, selected from the Atlantic Provinces. A list of land use planning and engineering adaptation tools follows the strategy description. These tools are described in documents *Part 2 Land Use Planning Tools Adaptation Options* and *Part 3 Coastal Intervention Options and Engineering Considerations*.

Chapter 4. Adaptation Approaches – Making a Suitable Choice highlights what a community can do to start adapting to climate change impacts at the coast. The section identifies the principles for an informed and effective adaptation plan, describes what a community needs to begin the adaptation planning process, and presents step-by-step guidance for adaptation decision-making.

Chapter 5. Coastal Systems and Compatibility of Adaptation Options describes the coastal systems of the Atlantic Provinces and suitable adaptation options for use in these environments. The nature and intensity of coastal processes in any given location, and the form and features of the coastal environment – the coastal system – influence the selection of adaptation tools to address a community's coastal issue(s). Understanding the characteristics and conditions of a coastal zone supports informed adaptation decision-making.

Chapter 1: Coastal Processes

Coasts are dynamic environments where tides flood and ebb and where land shifts and reforms in response to the energy of wind and waves. The interaction between the land and sea allows for the removal, transport and re-deposition of material within the coastal zone. Some coastal zones are more active than others, allowing for more material to be transported. Coastal processes such as waves, currents, tides, and storm surge are natural and only become a hazard when they impact coastal infrastructure, damaging buildings, roads, waterfronts, or wharfs. This chapter introduces natural coastal processes (i.e., erosion, sediment transport and deposition), their interaction with built structures in the coastal zone, and how these processes create the various coastal systems we see in Atlantic Canada.

The coastal zone is organized into sections or regions (Figure 1.1). The foreshore is the region between the high and low water marks. The nearshore region is where waves become steeper and break.

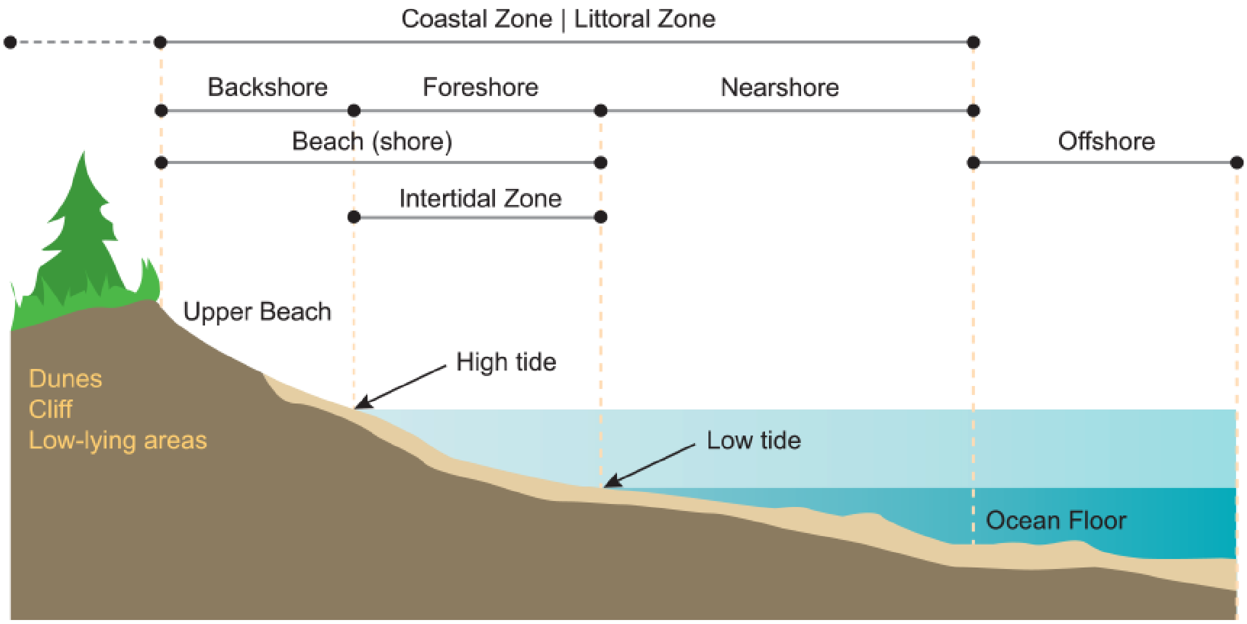

Figure 1.1 Key coastal zone terms (after Davidson-Arnott et al., 2019[1])

Water levels and waves are the principal features of the coastal zone that determine the evolution of coastal systems and that also define the processes of coastal hazards when development is located in the coastal zone. The littoral zone includes the full extent of the beach and nearshore and represents the region where sediment can be transported by waves.[2]

The following section covers natural coastal processes and how these processes create the various coastal systems in Atlantic Canada. The most appropriate management strategy for each coastal system (estuary, sandy beach, cliff etc.) will be discussed.

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[1] Davidson-Arnott, R., Bauer, B., and Houser, C. (2019). *Introduction to Coastal Processes and Geomorphology, Second Edition.* Cambridge University Press.
[2] Ibid.

1.1 Water levels

Water level is the height of the water relative to the shoreline and also the reach of the water inland. Water levels are influenced by the following components:

- **high tide**,
- **storm surge** (the increased water height due to storm conditions),
- **seiching** (how the shape of a bay affects the size of waves, e.g., long-wave oscillations in a semi-enclosed bay or harbour),
- **sea level rise** and other long-term influences such as land subsidence (land sinking because of geologic changes),
- **wave run-up** (the vertical distance a wave travels up the shoreline above still water level).

Table 1.1 describes the typical measurements and influencing factors for these water levels in Atlantic Canada.[3]

Table 1.1 Water level components in Atlantic Canada[4,5]

Water level component	Typical time scale	Typical range for Atlantic Canada	Main influencing factors
Tides	12.4 hours (semi-diurnal) to 24 hours (diurnal)	< 2 m (Atlantic coast, Gulf of Saint Lawrence) to 16 m (Upper Bay of Fundy)	Regional bathymetry (measurement of the depth of water) Phases of the moon and sun
Storm surge	Hours	Generally < 1.5 m, largest storms > 2 m	Site, storm intensity and duration
Seiching (bay or harbour)	Hours	Generally < 1 m	Bay or harbour dimensions
Sea level rise	Decades	75-100 cm by 2100 (relative to 1986–2005 for RCP8.5)	Global sea level rise, regional vertical crustal motion
Wave run-up	Hours	Depends on site-specific factors (nearshore wave climate, bathymetry, slope and slope roughness)	

[3] Davidson-Arnott, R., Bauer, B., and Houser, C. (2019). *Introduction to Coastal Processes and Geomorphology, Second Edition.* Cambridge University Press.
[4] Ibid.
[5] Dietz, S. and Arnold, S. (2021). Atlantic Provinces; Chapter 1 in *Canada in a Changing Climate: Regional Perspectives Report*, (ed.) F.J. Warren, N. Lulham and D.S. Lemmen; Government of Canada, Ottawa, Ontario.

1.2 Waves

Waves generated by wind are limited by ‘fetch’, which is the unimpeded distance that wind is able to blow over water. Moderate waves are generated over limited fetch distances in protected areas such as bays whereas large waves are generated over the open ocean.

Large offshore waves occur with every major storm. Near the coast, approaching wave crests bend towards the shoreline, become steeper, and ultimately break. The height of a breaking wave is limited by the water depth. Large waves can approach closer before breaking the steeper the shoreline is in the nearshore and foreshore zones, and the deeper the water is close to shore.[6]

Tsunami waves are large displacements of water caused by earthquakes, volcanoes, seabed slides, calving glaciers, and avalanches.[7] While they have occurred, tsunamis are rare in the Atlantic region; the most notable hit Newfoundland’s Burin Peninsula in November 1929 following an underwater landslide on the Grand Banks that was triggered by an earthquake.[8]

1.3 Currents

Currents are a continuous, directed horizontal movement of sea water. Currents occur at a wide range of scales, from ocean currents such as the Gulf Stream in the North Atlantic Ocean to local coastal currents influenced by the conditions of waves, tides, and winds. Many processes can generate coastal currents; the most common processes are summarized in Table 1.2.

Table 1.2 Coastal currents[9]

Current Type		**Characteristics**
Wave-driven	Longshore currents	Driven by waves breaking at an angle to the shoreline and causing longshore sediment transport
	Rip currents	Generated by localized differences in the water level caused by waves breaking over irregular sandbars along beaches
	Undertow	A bottom current that returns water from broken waves seaward
Tidal		Generated by slope in water surface due to the progressing tide, can be large in constricted areas such as tidal channels and inlets
Wind or seiche driven		Can be large during a large storm

[6] Davidson-Arnott, R., Bauer, B., and Houser, C. (2019). *Introduction to Coastal Processes and Geomorphology, Second Edition.* Cambridge University Press.
[7] Ibid.
[8] Higgins, J. (2007). The Tsunami of 1929. Heritage Newfoundland and Labrador. Retrieved from https://www.heritage.nf.ca/articles/politics/tsunami-1929.php
[9] Ibid.

1.4 Sediment transport and erosion

The energy released by waves in the nearshore causes sediment to move (sediment transport) both perpendicular to the shore and parallel to the shore. Sediment transport parallel to the shore (alongshore) is referred to as longshore transport (Figure 1.2); this is caused by longshore currents. Longshore transport is very important in order to move sediment from inputs (“sources”; e.g., bluffs, cliffs, or river mouths) to outputs (“sinks”), such as beach and dune systems or depositional features (e.g., barrier islands or spits). It is possible to look at sediment input and output as part of a “sediment budget”. When an area has an overall loss of sediment (negative sediment budget), it is eroding, whereas areas with positive sediment budgets are “accreting” or experiencing an overall gain in sediment. Sediment moves from sources to sinks within set boundaries called “littoral cells”; there can be more than one source or sink within a single littoral cell, but they are interconnected.

The manner in which sediment is transported depends on its grain size (which ranges from very fine silts and clays, to sand, gravel, and cobbles). Very fine sediment is generally transported in a different manner than the larger particle sizes because really fine grains have a cohesive nature and will stick together, where larger grains will not. Silts and clays tend to get “suspended” in (float around within) the water column and are deposited by settling in calm areas in the outer nearshore or offshore zones, or on mudflats and salt marshes in estuaries and lagoons. Non-cohesive sediments (sands, gravels, and cobbles) are set in motion by waves and currents. The larger the grain size, the more energy it takes to move them, so cobbles require very strong waves to be transported. Smaller, lighter grains (sands) can also be transported by the wind when they are dry (aeolian transport), and this is necessary in the formation of dunes.[10]

Erosion occurs due to the following natural coastal processes:

- Change in wave size or strength, change in the shape of land under the surface of the water (bathymetry), or change in direction that the waves strike the shore (orientation) can cause more sediment to be transported down the coast to a different site.
- Transport of sand offshore.
- Loss of sand inshore, caused by dune breaching; breaching occurs when a dune is eroded in a certain area and water flows through.
- Decreasing or lack of sand supply from rivers or cliffs, preventing a replenishment of what is being eroded.
- Instabilities of the seafloor such as landslides and slope failure that are caused by a combination of rain runoff and/or wave action with erosion occurring below the low tideline (this wave-driven erosion at the base of a bluff is irreversible and the fine sediments are lost to deep water).
- Retreating shorelines caused by sea level rise (shorelines typically match the increase in water level). The erosion rate is determined by sea level rise and many local factors such as geology and natural sediment supply.

[10] Ibid.

Figure 1.2 Illustration of longshore (parallel) sediment transport (modified from Google Earth[11])

People settle in the coastal zone for access to the ocean and its resources, for recreation, and the aesthetic environment. Some of the activities and infrastructure of settlement interfere with coastal processes, and coastal processes can become hazardous to these activities and infrastructure. Water levels and wave energy can interfere with, damage, or destroy the structures or land uses that people place in the coastal zone. People try to control coastal processes to either use them to their advantage (e.g., installing a groyne to capture sand in front of a property where sand does not normally collect) or to slow them down or stop them (e.g., building a seawall to stop erosion or dykes to stop tidal flooding). Many control structures can exacerbate the processes they are supposed to control, at the site of the control or locations further along the coast. They can interfere with the transfer of materials through erosion, longshore drift, and deposition. This means that the construction of a structure on one property could affect neighbouring properties that are within the same larger system or "littoral cell" because they depend on the same source(s) of sediment.

Erosion occurs due to the following human interference with natural coastal processes:

- Impermeable, shore-perpendicular structures (such as groynes or breakwaters) interrupt the movement of sand along a beach (longshore transport). When longshore transport is predominantly in one direction, there will be erosion on the opposite side of the structure from where the waves impact (lee side erosion) since the structure blocks downdrift transport alongshore (Figure 1.3). The length and angle of a structure in comparison to predominant wave direction as well as its position relative to the nearshore zone are the main factors influencing its effect on how the shoreline changes shape over time (shoreline morphology).
- Harbours catch the sand and thereby reduce downdrift supply.

[11] Google Earth. (n.d.). *Image of beach to illustrate longshore sediment transport.* [image]. Retrieved from https://www.google.com/earth/

- Shore-parallel structures (such as seawalls) block the transport of sand from the backshore to offshore sand bars during storms; erosion, caused by the flow of water, occurs at the foot of the structure instead (scour).
- Removal of sand by-sand mining or dredging.

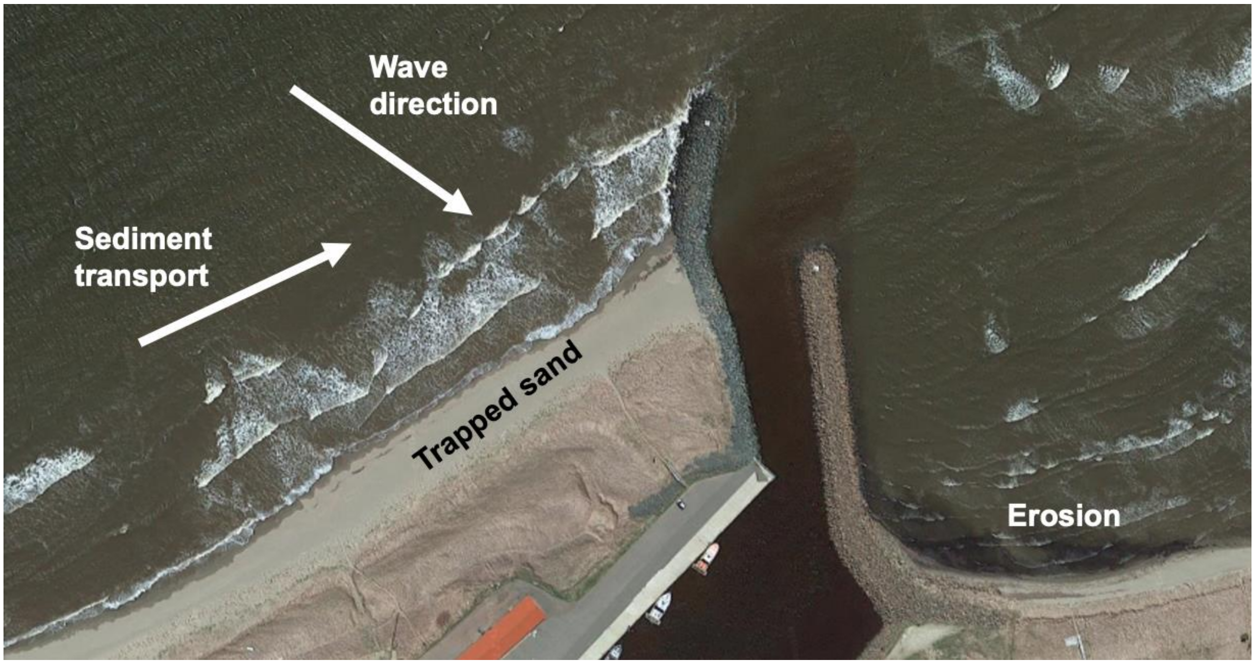

Figure 1.3 Accretion (trapped sand) and erosion at shore-perpendicular structures. Engineered structures can interfere with natural flow and sediment processes and may have unintended consequences further down the coast (Google Earth, 2022)

Chapter 2: Climate Change and Coastal Hazards

2.1 Climate change and sea level rise

Roughly 2.4 million people live in the Atlantic Provinces (as of 2021[12]), with the majority in cities and rural towns and villages located along the coast (Table 2.1). All of the region's coastal communities are vulnerable to the impacts of climate change to some extent.

Sea level rise and storm surge causing coastal flooding are the dominant climate change impacts for coastal communities. Atlantic Canada is faced with multiple climate change threats and challenges as a result of rising sea levels including coastal flooding, erosion, loss of intertidal habitat, salt marsh migration, storm surge damage to infrastructure, and winter ice loss in some areas with a consequent increase in shoreline scour.[13,14,15] Coastal flooding and erosion are of particular concern, as the coastlines of the Atlantic Provinces are vulnerable to these impacts.

Table 2.1 Overview of the coastal population, length of coastline, and coastal ecosystems of each Atlantic Province[16,17,18]

New Brunswick	Population: 775,610 (2021 Census) Percentage of population within 10km of the coast: 32% Coastline: 2,700 km Coastal Ecosystems: estuaries, coastal sandy systems, intertidal flats, salt marshes, cobble beaches, banks, cliff/bluffs, and rocky shores
Nova Scotia	Population: 969,383 (2021 Census) Percentage of population within 10km of the coast: 82% Coastline: 13,000 km Coastal Ecosystems: estuaries, coastal sandy systems, intertidal flats, salt marshes, cobble beaches, banks, cliff/bluffs, and rocky shores
Prince Edward Island	Population: 154,331 (2021 Census) Percentage of population within 10km of the coast: 97% Coastline: 1,400 km Coastal Ecosystems: estuaries, coastal sandy systems, intertidal flats, salt marshes, banks, and cliff/bluffs

[12] Statistics Canada. (2022). Population and dwelling counts: Canada, provinces and territories. Accessed April, 2022. Source: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=9810000101
[13] Davies, M. (2011). Geomorphic Shoreline Classification of Prince Edward Island. Report prepared by Coldwater Consulting Ltd for the Atlantic Climate Adaptation Solutions Associations (ACASA), 66 pp.
[14] Arlington Group. (2013). Sea Level Rise Adaptation Primer: A toolkit to build adaptive capacity on Canada's South Coasts. Report prepared for British Columbia Ministry of Environment, 150 pp.
[15] Canada National Round Table on the Environment and the Economy (NRTEE). (2011). Paying the Price: The Economic Impacts of Climate Change for Canada. National Round Table on the Environment and the Economy, 168 pp.
[16] Arlington Group. (2013). Sea Level Rise Adaptation Primer: A toolkit to build adaptive capacity on Canada's South Coasts. Report prepared for British Columbia Ministry of Environment, 150 pp.
[17] Ganter, S., Crawford, T., Irwin, C., Robichaud, V., DeMaio-Sukic, A., Wang, J., Andrews, J., and Larocque, H. (2021). Canada's oceans and the economic contribution of marine sectors. Statistics Canada – Catalogue no. 16-002-X. Accessed May, 2022. Source: https://www150.statcan.gc.ca/n1/en/pub/16-002-x/2021001/article/00001-eng.pdf?st=FLl64jG7
[18] Statistics Canada. (2022). Population and dwelling counts: Canada, provinces and territories. Accessed April, 2022. Source: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=9810000101

Newfoundland and Labrador	Population: 510,550 (2021 Census) Percentage of population within 10km of the coast: 87% Coastline: 25,900 km Coastal Ecosystems: estuaries, coastal sandy systems, intertidal flats, salt marshes, cobble beaches, banks, cliff/bluffs, and rocky shores

Global sea level rise is attributed to thermal expansion of warming ocean water and the melting of inland glaciers and the Antarctic and Greenland ice sheets. Sea level rise is relative to local conditions and is highly variable. Relative sea level rise includes the change in the ocean water level as well as the change in the elevation of the land compared to its present elevation.[19]

The landmass of the Atlantic Provinces is still adjusting to the retreat of glaciers that took place 15,000 to 10,000 years ago. As the ice sheet that once covered the area retreated (melted away), the earth's crust adjusted: the land that emerged from in front of the ice rose up, responding to the release in pressure, and also because the ice was still pressing down on the land behind it. As the ice continued to recede further away, the landmass of the Atlantic Region started to settle back down again. This is called isostatic adjustment, or post-glacial rebound or subsidence, and the rate is uneven across the region. Most of the populated coast of the Atlantic Provinces is subsiding (sinking), however some areas are experiencing uplift (rising), particularly around northern and western New Brunswick as well as part of Newfoundland and Labrador (Figure 1.4).[20] This variation in subsidence also means that the rate of change in sea level (relative sea level rise - RSLR) is not consistent throughout the region, with the highest RSLR occurring in those areas of the Maritimes experiencing the highest rates of subsidence (Figure 1.5).[21]

[19] James, T.S., Robin, C., Henton, J.A., and Craymer, M. (2021). Relative sea-level projections for Canada based on the IPCC Fifth Assessment Report and the NAD83v70VG national crustal velocity model; Geological Survey of Canada, Open File 8764. https://doi.org/10.4095/327878

[20] Arlington Group. (2013). Sea Level Rise Adaptation Primer: A toolkit to build adaptive capacity on Canada's South Coasts. Report prepared for British Columbia Ministry of Environment, 150 pp.

[21] James, T.S., Robin, C., Henton, J.A., and Craymer, M. (2021). Relative sea-level projections for Canada based on the IPCC Fifth Assessment Report and the NAD83v70VG national crustal velocity model; Geological Survey of Canada, Open File 8764. https://doi.org/10.4095/327878

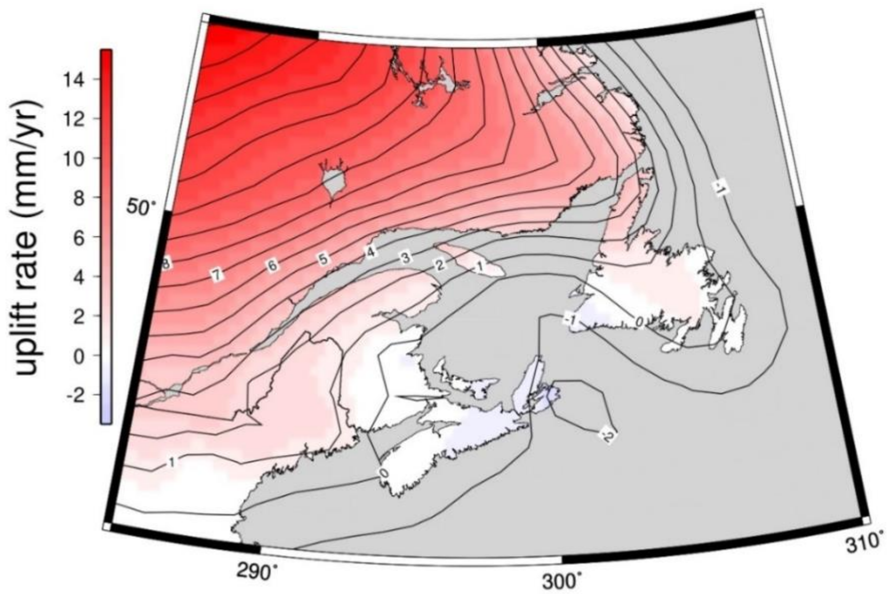

Figure 1.4 Glacial isostatic adjustment in Atlantic Canada; rates of uplift and subsidence (based on Robin et al.[22])

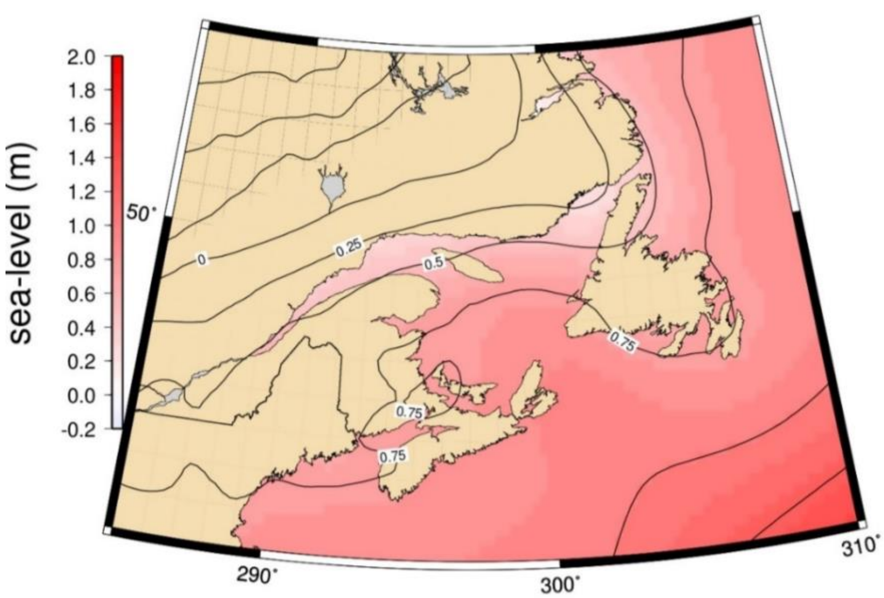

Figure 1.5 Projections of relative sea-level rise by the year 2100 for RCP8.5 (based on James et al.[23])

The areas of the Atlantic Provinces most sensitive to sea level rise and the resulting physical changes are along the Gulf of St. Lawrence coast of New Brunswick, the north shore of Prince Edward Island, and the southern coast and low-lying areas of Nova Scotia and the upper Bay of

[22] Robin, C.M.I., Craymer, M., Ferland, R., James, T.S., Lapelle, E., Piraszewski, M., and Zhao, Y. (2020). NAD83v70VG: A new national crustal velocity model for Canada; Geomatics Canada, Open File 0062. https://doi.org/10.4095/327592
[23] James, T.S., Robin, C., Henton, J.A., and Craymer, M. (2021). Relative sea-level projections for Canada based on the IPCC Fifth Assessment Report and the NAD83v70VG national crustal velocity model; Geological Survey of Canada, Open File 8764. https://doi.org/10.4095/327878

Fundy where tidal fluctuations occur.[24,25,26] The tidal range in the Bay of Fundy can reach 16m, and such a range means that the additional component of tidal expansion due to sea level rise will increase the height of these tides in the future.[27] Even without the added effects of climate change, tidal expansion will add an additional 0.3 m to high tide levels in the Bay of Fundy over the next century.[28]

Climate change impacts on waves and water levels in Atlantic Canada will increase flooding and erosion hazards (Figure 1.6).

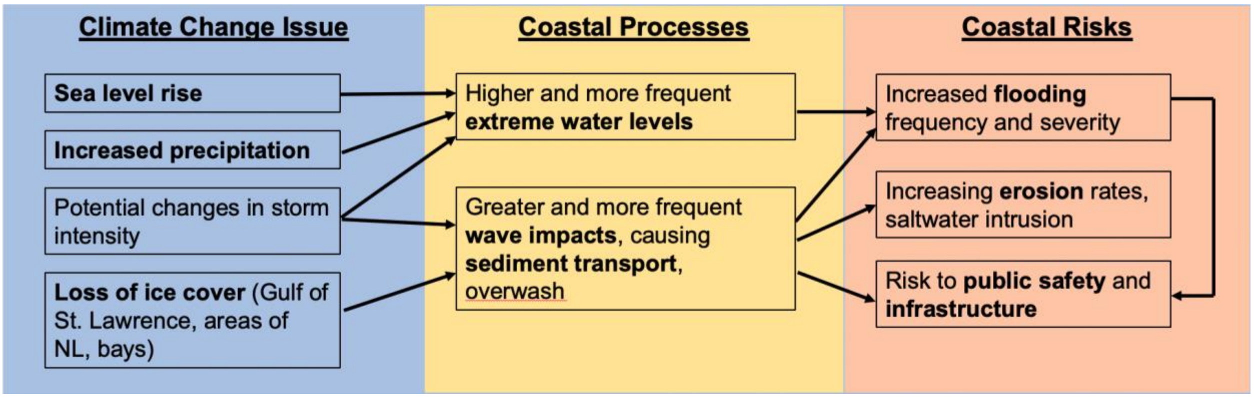

Figure 1.6 Climate change impacts on coastal hazards (Vincent Leys, CBCL Limited)

[24] Daigle, R.J. (2011). Coastal Flooding Issues. Report submitted to the Atlantic Climate Adaptation Solutions Association (ACASA), 12 pp.
[25] Davidson-Arnott, R. and Ollerhead, J. (2011). Coastal Erosion and Climate Change. Report prepared by Prince Edward Island Department of Environment, Labour and Justice for the Atlantic Climate Adaptation Solutions Association (ACASA), 41 pp.
[26] Arlington Group. (2013). Sea Level Rise Adaptation Primer: A toolkit to build adaptive capacity on Canada's South Coasts. Report prepared for British Columbia Ministry of Environment, 150 pp.
[27] Schauffler, F.M. (2014). Municipal Climate Change Adaptation around the Bay of Fundy: Status and Needs. Report prepared for the Gulf of Maine Council on the Marine Environment. 42 pp.
[28] Greenberg, D.A., Blanchard, W., Smith, B., and Barrow, E. (2012). Climate Change, Mean Sea Level and High Tides in the Bay of Fundy. Atmosphere-Ocean, 50(3), 261-276, DOI: 10.1080/07055900.2012.668670

2.2 Coastal flooding

While sea level rise will flood low-lying coastal land, the flood risk increases with the increasing intensity of storms.[29] As storms travel up the Atlantic Coast, the intense low-pressure, high wind speeds, long fetch (distance over which wind can blow without being obstructed), tidal conditions, and coastal orientation promote the development of a storm surge.[30] Storm surge can cause extensive flooding within an area, posing a significant risk to coastal ecosystems, infrastructure, and communities located within the extent of the surge. Storm surge flooding is a concern regardless of sea level rise, but sea level rise means that areas previously unaffected by storm surge will be in the flood zone in the future, and more intense storms will push the storm surge further inland. The greatest flooding from storm surge occurs when the surge arrives with high tide (Figure 1.7; Figure 1.8).

Figure 1.7 Extent of storm surge flooding in North Rustico, PEI, December 21-22, 2010 (Don Jardine)

Figure 1.8 Storm surge in Louisbourg, NS during Hurricane Fiona, September 24, 2022 (Paul Daroux)

[29] Daigle, R.J. (2011). Coastal Flooding Issues. Report submitted to the Atlantic Climate Adaptation Solutions Association (ACASA), 12 pp.
[30] Woth, K., Weisse, R., & von Stroch, H. (2005). Dynamical modelling of North Sea storm surge extremes under climate change conditions – an ensemble study. Report 2005/1, GKSS – Forschungzentrum Geesthacht GmbH, Geesthacht. 31 pp.

As a natural response to increasing water levels due to sea level rise, coastal systems (salt marshes, dunes, and beaches) are able to move landward. “Coastal squeeze” is the inability of these natural coastal environments to migrate landward[31,32,33,34] as a result of a constructed (e.g., dyke, road, seawall) or natural (e.g., cliff) barrier blocking the way (Figure 1.9). The increase in the presence of hard built structures, such as buildings, wharfs, and roads, along the coast has magnified the issue of coastal squeeze. When these natural systems are prevented from migrating landward and are therefore unable to keep pace with sea level rise, they begin to be eroded (beaches, dunes) or be submerged (salt marshes). As such, the area of valuable coastal ecosystems will be reduced.[35,36,37,38]

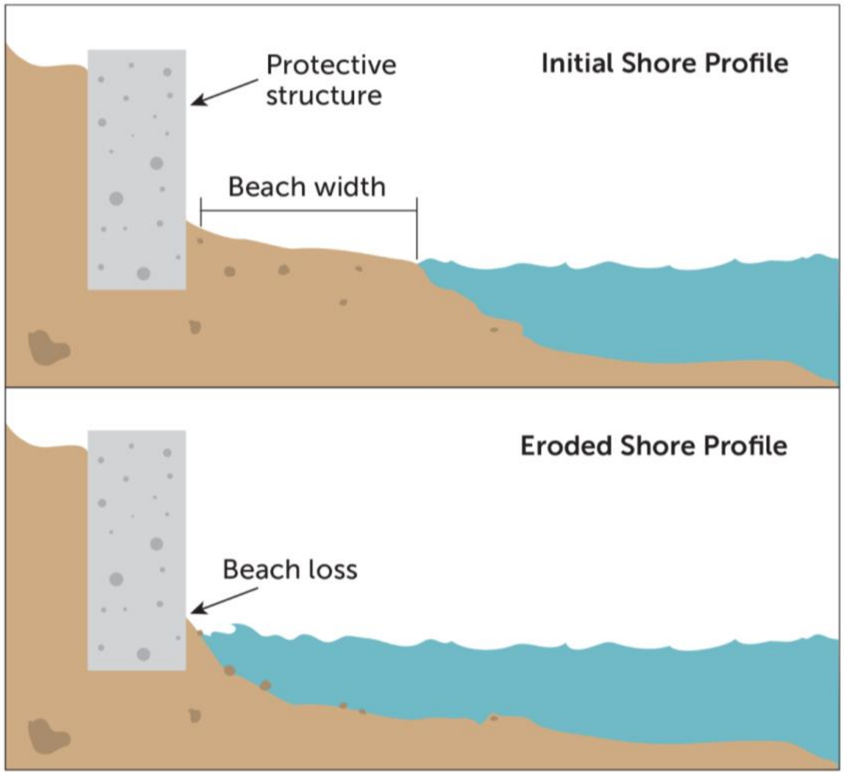

Figure 1.9 Coastal squeeze when protective structure is in place (modified from Tait and Griggs)[39]

[31] Doody, J. (2013). Coastal Squeeze and Managed Realignment in Southeast England, does it tell us anything about the future? *Ocean & Coastal Management, 79*, 34-41.
[32] Torio, D.D., and Chmura, G.L. (2013). Assessing coastal squeeze of tidal wetlands. *Journal of Coastal Research, 29 (5)*, p. 1049-1061.
[33] Bernatchez, P., and Fraser, C. (2012). Evolution of Coastal Defence Structures and Consequences for Beach Width Trends, Québec, Canada. *Journal of Coastal Research, 28(6)*, 1550-1566.
[34] Jolicoeur, S., and O’Carroll, S. (2007). Sandy barriers, climate change and long-term planning of strategic coastal infrastructures, Îles-de-la-Madeleine, Gulf of St. Lawrence (Québec, Canada). *Landscape and Urban Planning, 81*, pp. 287-298.
[35] Doody, J. (2013). Coastal Squeeze and Managed Realignment in Southeast England, does it tell us anything about the future? *Ocean & Coastal Management, 79*, 34-41.
[36] Torio, D.D., and Chmura, G.L. (2013). Assessing coastal squeeze of tidal wetlands. *Journal of Coastal Research, 29 (5)*, p. 1049-1061.
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[38] Jolicoeur, S., and O’Carroll, S. (2007). Sandy barriers, climate change and long-term planning of strategic coastal infrastructures, Îles-de-la-Madeleine, Gulf of St. Lawrence (Québec, Canada). *Landscape and Urban Planning, 81*, pp. 287-298.
[39] Tait, J.F., & Griggs, G.B. (1991). Beach response to the presence of a seawall; Comparison of field observations. Prepared for Department of the Army, US Army Corps of Engineers. pp 61-62.

2.3 Coastal erosion

The region is also at significant risk to coastal erosion due to the expanded inland reach of tidal and wave actions that result from rising sea levels. Vulnerability to erosion is determined mainly by what the shoreline is made up of (geological composition) as some materials are more resistant than others (e.g., granite versus loose soil). Other factors that influence erosion are wave exposure, winter ice formation, freeze/thaw during winter and spring, and inland water drainage. Significant sections of the Atlantic coast of Nova Scotia (most notably Cape Breton) and Newfoundland and Labrador are comprised of resistant bedrock that erodes at a very slow pace over decades, although it increases runoff and can make inland flooding worse. In contrast, the geology of Prince Edward Island is dominated by sandstone that is highly susceptible to erosion.[40] The Gulf of St. Lawrence coast of New Brunswick and many areas of coastal Nova Scotia (especially the Northumberland Strait shore, the Bay of Fundy, and the Eastern Shore) are also susceptible to erosion.

While each site is unique in terms of its geology and coastal processes, coastal climate change impacts in the Atlantic region are characterized by the following trends:

- Storm surges are highest in the Northumberland Strait, where the tidal range is relatively limited. Therefore, a strong storm surge can have an impact at most stages of the tide. This affects Nova Scotia's North Shore, Prince Edward Island and Eastern New Brunswick. Storm surges will continue to affect these coasts as sea levels rise.
- The Bay of Fundy's huge tidal range somewhat decreases the likelihood of storm surges hitting at high tide and causing damage. However, infrequent occurrences of a storm surge coinciding with an extreme high tide can have a particularly strong impact.
- The Gulf of Saint Lawrence will be impacted by the loss of sea ice cover, with increased wave impacts and erosion in the winter.
- Extreme weather has always been associated with Atlantic Canada, but recent predictions indicate that it will become stronger and more frequent with climate change. In the last two decades, three quarters of hurricane seasons had above-average storm activity. As hurricanes enter the region's cold offshore waters, they usually lose energy and are downgraded. However, with warming ocean temperatures, hurricanes will be able to maintain energy. In 2010/2011, hurricanes made landfall in Newfoundland and Labrador in two consecutive years for the first time in the province's history.[41] Furthermore, in 2022, Hurricane Fiona made landfall in Nova Scotia as an extratropical cyclone with sustained winds comparable to that of a Category 2 hurricane. It is likely the strongest storm in Canadian history as gauged by barometric pressure.[42]

[40] Davidson-Arnott, R. and Ollerhead, J. (2011). Coastal Erosion and Climate Change. Report prepared by Prince Edward Island Department of Environment, Labour and Justice for the Atlantic Climate Adaptation Solutions Association (ACASA), 41 pp.
[41] Province of Newfoundland and Labrador. (2013). Turn Back the Tide: Impacts of Climate Change. Website of the Office of Climate Change and Energy Efficiency. Accessed December, 2014. Source: http://www.turnbackthetide.ca/understanding/impacts-of-climate-change.shtml#.VJLPnnv3Gf4
[42] Fogarty, C., R. Mercer, and P. Courtier, Philippe. "Tropical Cyclone Information Statement For Eastern Canada Updated By Environment Canada At 6:43 P.M. ADT Sunday 25 September 2022" (Tropical Cyclone Information Statement). Environment Canada. Retrieved October 10, 2022.

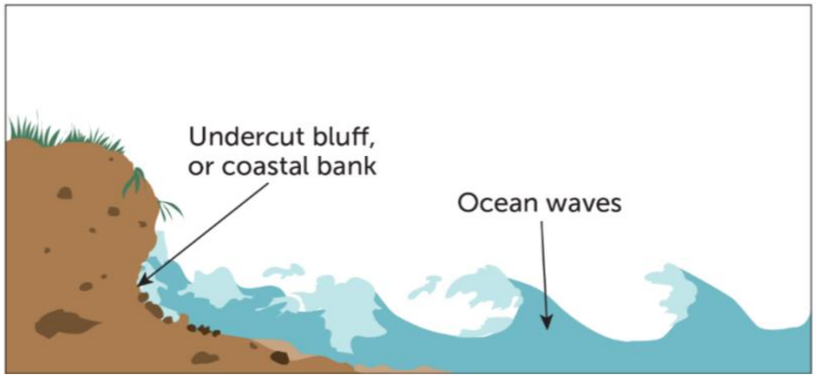

Figure 1.10 Erosion process of undercutting by waves (modified from Nelson[1])

Erosion can take place as waves hit the bottom (toe) of the cliff, bluff, or bank. This erosion is called "undercutting" (Figure 1.10). When this happens, the toe of the cliff or bluff weakens because of the loss of material. Undercutting can lead to slumping or collapsing of the cliff, bluff, or bank since the weight of the material above the undercut area is no longer well supported. Erosion can also take place as water seeps and flows down into and along the face of cliffs and bluffs from the land above. This is particularly a concern during high intensity rainfall events. As water accumulates and pools above, it can begin to cut or tunnel, creating natural drainage networks through the soil. These rills and gullies can cause considerable damage along easily erodible coastal features (Figure 1.11). 'Piping' (groundwater seepage) can also occur within the exposed slope where groundwater seeps out of the bluff face.

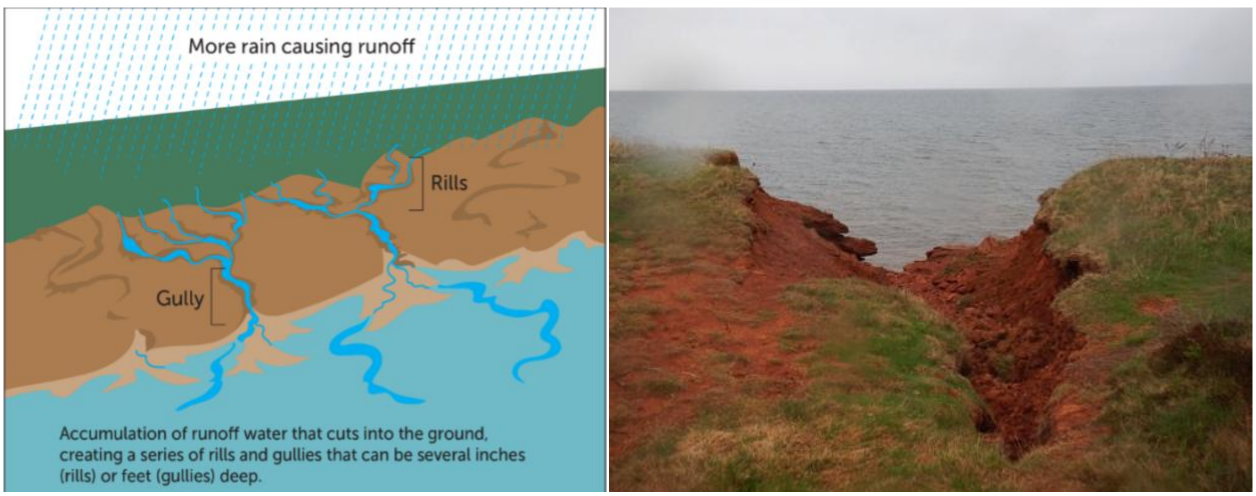

Figure 1.11a erosion process of gullying (modified from Northern Virginia Soil and Water Conservation District[1]) and 1.11b an example of gullying erosion in PEI (Samantha Page)

Climate change-induced sea level rise could lead to an increase in toe erosion due to the higher water level allowing more and larger waves to reach the base of cliffs and bluffs more often. Where tall cliffs are made of harder rock material, this would simply change (increase) the level on the cliff face where erosion generally takes place. But for cliffs made of softer materials and bluffs, an increase in toe erosion would lead to higher overall cliff and bluff erosion rates. This is particularly concerning for properties and infrastructure located on top of them and makes land use restrictions and setbacks as well as retreat all the more important in order to adapt and keep people safe.[43]

[43] Davidson-Arnott, R., Bauer, B., and Houser, C. (2019). *Introduction to Coastal Processes and Geomorphology, Second Edition.* Cambridge University Press.

Chapter 3: Adaptation Strategies

Atlantic Canadians living in coastal communities are seasoned veterans when it comes to dealing with the risks associated with storm surge, flooding, and erosion. Climate change induced sea level rise will make hazards worse (e.g., flooding, erosion), as it will result in changes to the strength of coastal processes (e.g., wave and water levels) while increasing storm intensity and risk for coastal communities.[44,45,46] To decrease the risk of coastal hazards, communities must increase their ability to respond to these hazards, recover, and adapt to future change. This ability to respond, recover, and adapt is referred to as resilience. Education about coastal management strategies and approaches can help build resilience.

Studies show that it is cheaper for communities to prevent or plan adaptation to the impacts of coastal hazards such as flooding and erosion.[47,48,49,50] It is in a community's best interest to begin the process as soon as possible since implementing an adaptation strategy requires considerable effort and time from both community decision-makers and stakeholders.

There are four main strategies for use in coastal climate change adaptation: **Avoid, Retreat, Accommodate, Protect Approaches**. Land use planning and engineering provide a variety of tools to use in each of these strategies. These tools fit into categories: capacity building, planning framework, regulation and land use change, and site design tools for land use planning; and erosion management, flood management and hybrid tools for engineered coastal intervention approaches. Table 3.1 summarizes the tool categories. These categories are also used to organize the tools in the companion guidance documents, *Part 2 Land Use Planning Tools Adaptation Options*, and *Part 3 Coastal Intervention Options and Engineering Considerations.*

Adaptation - in human systems, it is the process of adjustment to actual or expected climate and its effects in order to moderate harm or take advantage of beneficial opportunities. In natural systems, adaptation is the process of adjustment to actual climate and its effects; human intervention may facilitate this.[44]

[44] IPCC, 2022: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Pörtner, H.-O.; Roberts, D.C.; Tignor, M.; Poloczanska, E.S.; Mintenbeck, K.; Alegría, A.; Craig, M.; Langsdorf, S.; Löschke, S.; Möller, V.; Okem, A.; and Rama, B. (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp

[45] Cardona, O.D., van Aalst, M.K., Birkmann, J., Fordham, M., McGregor, G., Perez, R., Pulwarty, R.S., Schipper, E.L.F., and Sinh, B.T. (2012). Determinants of risk: exposure and vulnerability. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor and P.M. Midgley (Eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge, UK and New York, NY: Cambridge University Press, pp. 65-108.

[46] Magnan, A. (2014) Avoiding maladaptation to climate change: towards guiding prinicples. S.A.P.I.EN.S, 7(1). Retrieved from: https://sapiens.revues.org/1680

[47] Canada National Round Table on the Environment and the Economy (NRTEE). (2011). Paying the Price: The Economic Impacts of Climate Change for Canada. National Round Table on the Environment and the Economy, 168 pp.

[48] Brown, A., Gawith, M., Lonsdale, K., and Pringle, P. (2011). Managing adaptation: linking theory and practice. UK Climate Impacts Programme, Oxford, UK.

[49] Linham, M. M., & Nicholls, R. J. (2010). Technologies for Climate Change Adaptation: Coastal Erosion and Flooding. UNEP Risø Centre on Energy, Climate and Sustainable Development, 166 pp.

[50] IPCC, 2022: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Pörtner, H.-O.; Roberts, D.C.; Tignor, M.; Poloczanska, E.S.; Mintenbeck, K.; Alegría, A.; Craig, M.; Langsdorf, S.; Löschke, S.; Möller, V.; Okem, A.; and Rama, B. (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp

The following sections describe the importance of understanding risks and the four adaptation strategies. Each is described with illustrated examples, including a list of tools that support the strategies. Tools can support more than one strategy. For example, fibre coir logs, sills, groynes, or breakwaters may be used in combination with sand, other natural materials, and/or marsh plantings – a living shoreline coastal intervention – to 'accommodate' a change in coastal use and 'protect' landward uses by stabilizing the shoreline and decreasing wave energy reaching the shore.

Land use planning and coastal interventions can be used alone or in combination to extend the effectiveness of each tool. A seawall provides temporary protection for a vulnerable land use while a land acquisition program amasses enough property to support relocation of structures to safer, higher land. Also, climate change adaptation plans will include diverse strategies and tools to address different coastal climate change challenges in a community.[51,52] Solutions are site specific and will require a combination of approaches.

Table 3.1 Land use planning and engineering tools for climate change adaptation at the coast

Land Use Planning Tools *(see: Part 2 Land Use Planning Tools Adaptation Options)*
Capacity Building Tools: Enhance a community's or individual's knowledge and understanding of its local, coastal environment, including its coastal habitats, climate change impacts, vulnerability and risks, and community assets and ability to make sound decisions and take appropriate actions to respond to any opportunities and risks associated with climate change.
Planning Framework Tools: Used by local and regional governments to guide, implement and administer land use planning and emergency planning.
Regulations and Land Use Change Tools: Allow communities to regulate land use and the subdivision of land or change the use or ownership of land.
Site Design Tools: Enable communities to incorporate site characteristics into coastal planning and design.
Engineered Coastal Interventions *(see: Part 3 Coastal Intervention Options and Engineering Considerations)*
Erosion Management Tools: Reduce or prevent erosion from occurring within the coastal zone.
Flood Management Tools: Reduce or prevent the effects of flood water occurring within the coastal zone.
Erosion and Flooding Tools: Can reduce or prevent both flooding and erosion.

[51] Leys, V., v. d. Heuvel, S. Kaji, A. 2023. Coastal Adaptation Toolkit, Adapting to Climate Change in Coastal Communities of Atlantic Canada. Part 3 Coastal Intervention Options and Engineering Considerations. https://climatlantic.ca/coastal-adaptation/

[52] Manuel, P., DeVidi, M. 2023. Coastal Adaptation Toolkit, Adapting to Climate Change in Coastal Communities of Atlantic Canada. Part 2 Land Use Planning Tools & Adaptation Options. CLIMAtlantic. https://climatlantic.ca/coastal-adaptation/

3.1 Understanding risk

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

Adaptation tools used in this strategy are capacity building, planning framework, regulations and land use change, and site design tools. These same categories of tools also work for accommodation, retreat, and/or avoidance approaches.

Table 3.2 "Understanding Risk" Strategy Tools

Land Use Planning Tools	Capacity Building	Data gathering and mapping
		Partnerships
		Local committees
		Vulnerability assessment
		Community asset mapping
		Education
		Visioning
		Community engagement
	Planning Framework	Emergency preparedness
		Regional plan (non-statutory), land use policy
		Integrated community sustainability plan
		Climate change action/adaptation plan
		Shoreline/coastal management plan
		Watershed management plan
		Strategic land acquisition (land bank)
		Wetland policy
	Regulations and Land Use Change	Wetland regulation
		Statutory community plan
		Tax or development incentive
		Foreshore lease
	Site Design	Coastal development rating system
		Site monitoring

Example: Bras D’or Lakes, Cape Breton, Nova Scotia

Scientists with the Geological Survey of Canada mapped and assessed the coastal geographic and geologic features, including submerged coastal features of East Bay, Bras D’or Lakes. They reported their work in *Sensitivity of the Coasts of the Bras D’or Lakes to Sea-level-rise*.[53] Information gathering, mapping, and assessment are capacity building tools that support adaptation planning. The assessment presents historic and future sea level trends and a coastline classification system. The coastal geography includes cliff, beach, outcrop, vegetated, and barrier systems. The scientists identified the potential impacts of sea level rise on each coastal system, paying special attention to the barrier systems because of their complex development, breakdown, and regrowth. They proposed investigation of retreat, accommodate, and protect strategies for the East Bay coastal environment with attention to the features and processes of each coastal system.[54]

Example: Îles-de-la-Madeleine

The Îles-de-la-Madeleine are vulnerable to coastal hazards, particularly coastal erosion. The coastal geomorphology of these islands is very similar to coasts in New Brunswick, Nova Scotia, and PEI, with comparable hazards. Infrastructure is threatened by coastal retreat at several sites, such as the main road network of the archipelago (Route 199), (Figure 1.12) and the sewage purification ponds of the main community. In its *Master Plan*, the municipality of Îles-de-la-Madeleine identified 23 areas where erosion is an issue and where action is deemed necessary.[55] To integrate future changes in climate, Bernatchez et al.[56] proposed three future positions of the coastline (year 2050); these positions are based on historical erosion rates and were calculated using aerial photographs. Mapping the three coastline scenarios allowed stakeholders, scientists, and members of working groups to identify adaptation options for targeted priority sites.

The process demonstrated that coastal erosion exacerbated by climate change is a chronic and serious problem in the Îles-de-la-Madeleine.

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[53] Shaw, J., Taylor, R. B., Patton, E., Potter, D. P., Parkes, G. S., & Hayward, S. (2006). Sensitivity of the Coasts of the Bras D’or Lakes to Sea-Level Rise. Report prepared for the Geological Survey of Canada (Atlantic) through the Bedford Institute of Oceanography, 2006, 99 pp.
[54] Ibid.
[55] Municipalité des Îles-de-la-Madeleine. (2010). Plan d’urbanisme: Règlement No 2010-24. Municipalité des Îles-de-la-Madeleine, 60 pp. Retrieved from: http://www.muniles.ca/images/Upload/3_services_municipaux/2_greffe/3_reglementation_municipale/plan_reglements_urbanisme/plan_d__urbanisme_-_decembre_2010_correction.pdf.
[56] Bernatchez, P., Fraser, C., Friesinger, S., Jolivet, Y., Dugas, S., Drezja, S., and Morisette, A. (2008). Sensibilité des côtes et vulnérabilité des communautés du golfe de Saint-Laurent aux impacts des changements climatiques. *Laboratoire de dynamique et de gestion intégrée des zones côtières, Université du Québec à Rimouski.*

Figure 1.12 Île du Havre-aux-Maisons, Îles de la Madeleine, 2012 (Philip Giles, Saint Mary's University)

In 2016, the municipality of Îles-de-la-Madeleine created a permanent commission on bank erosion.[57] This commission laid out six priority sites across the archipelago in planning of erosion control measures, including: La Grave historic site, the city centre of Cap-aux-Meules, Entry Island, Gros-Cap Road, Gros-Cap campground, and the old dump in Fatima.[58] As of 2022, erosion management measures have been funded at four of the six sites.[59] A gravel beach nourishment project was completed at La Grave historic site in 2022, thanks to combined funding from the Government of Québec ministries of Public Safety and Transport as well as municipal funding.[60] Funding from Transport Québec is provided for protective measures (also gravel nourishment) in the Cap-aux-Meules city centre as well as along Gros-Cap Road, and the ministry of Tourism has announced funding for protective measures at Gros-Cap campground.[61] Transport Québec also announced funding for projects in locations beyond the commission's priority sites, with a particular emphasis on protection of Route 199[62], as this is the only road connecting the main islands of the archipelago to one another, making it critical infrastructure.

[57] Municipalité des Îles-de-la-Madeleine. (2016). Érosion des berges : Une commission permanente sera bientôt créée. Retrieved from: https://www.ilesdelamadeleine.com/2016/06/erosion-des-berges-une-commission-permanente-sera-bientot-creee/
[58] Grenier, P. (2018). Érosion aux Îles-de-la-Madeleine : « un éternel recommencement ». Radio-Canada. Retrieved from: https://ici.radio-canada.ca/nouvelle/1085665/berges-cap-aux-meules-la-grave-changement-climatique-havre-aubert
[59] Fautaux, H. (2022). Érosion : les Îles-de-la-Madeleine ont perdu plus de 8 mètres depuis 2005. *Le Journal de Montréal.* Retrieved from: https://www.journaldemontreal.com/2022/06/12/erosion-les-iles-de-la-madeleine-ont-perdu-plus-de-8-metres-depuis-2005
[60] Municipalité des Îles-de-la-Madeleine. (2022). Site historique de La Grave : Les travaux de recharge de plage sont terminés. Ilesdelamadeleine.com Retrieved from https://www.ilesdelamadeleine.com/2022/06/site-historique-de-la-grave-les-travaux-de-recharge-de-plage-sont-termines/
[61] Larose, I. (2022). Québec finance un autre projet de lutte contre l'érosion aux Îles-de-la-Madeleine. *Radio Canada.* Retrieved from: https://ici.radio-canada.ca/nouvelle/1855518/erosion-iles-de-la-madeleine-chantier-grop-cap-report-echeancier-falaises-ca-meules
[62] Larose, I. (2022). Plus de 50 M$ investis pour contrer l'érosion des îles de la Madeleine depuis 2018. *Radio Canada.* Retrieved from: https://ici.radio-canada.ca/nouvelle/1868049/chantier-protection-erosion-iles-madeleine-mtq-50-millions-municipalite-la-grave-falaise-cap-meules

3.2 Avoid

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.

Table 3.3 'Avoid' Strategy Tools

Land Use Planning Tools	Planning Framework	Regional plan (non-statutory), land use policy
		Integrated community sustainability plan
		Climate change action/adaptation plan
		Shoreline/coastal management plan
		Watershed management plan
		Strategic land acquisition (land bank)
		Wetland policy
	Regulations and Land Use Change	Wetland regulation
		Statutory community plan
		Tax or development incentive
		Zoning
		Setbacks
		Subdivision by-laws or regulations
		Transfer of development credits
		Land swap
		Development standards
		Development agreements
		Land use conversion and re-development
		Land trust
		Rolling easements
		Conservation easements
		Conservation legislation
	Site Design	Urban design standards
		Stormwater management
		Conservation subdivision design

<u>Example: Nova Scotia</u>

Some municipalities in Nova Scotia have designated development setbacks to avoid development close to coastal wetland or watercourse areas. Established setback measurements range from total developmental restrictions (e.g., Yarmouth, Argyle) to no restrictions at all (e.g., Digby, Colchester County). Typical setback measurements range from 10 to 30 metres from coastal wetlands or watercourses and in some instances, there are vertical setbacks as well that restrict development height above sea level.[63]

On a provincial level, the Coastal Protection Act, passed in 2019, creates a Coastal Protection Zone in which both vertical and site-specific horizontal setbacks apply over an 80-year planning horizon. Vertical setbacks, known as minimum building elevations, are a measurement above mean sea level designed to reduce flooding risks and include adjustments for local tides, projected relative sea level rise, and an additional storm surge allowance. Horizontal setbacks are designed to reduce erosion risks and set a minimum (horizontal) distance inland beyond the high-water mark, and are site-specific, depending on local conditions determined by a designated professional in terms of erodibility, slope stability, and sea level rise; this setback will not exceed the distance set for the Coastal Protection Zone. Additionally, within a horizontal area of 80-100 metres from the high-water mark, assessments will be required for all new construction as well as potentially for substantial alteration to existing development; development within this area will require a permit issued only after assessment has been completed.[64]

[63] Tipton, E. (2012). Coastal Management Strategy: The Municipality of the District of Shelburne Integrated Community Sustainability Plan. 42 pp.
[64] Nova Scotia Department of Environment and Climate Change. (2021). Part 2: A Detailed Guide to Proposed Coastal Protection Act Regulations. Retrieved from: https://novascotia.ca/coast/docs/part-2-detailed-guide-to-proposed-Coastal-Protection-Act-Regulations.pdf

3.3 Retreat (‘relocate the line’)

Retreat is a strategy to relocate people and infrastructure away from hazardous coastal areas to areas with lower risks. The strategy is a long-term adaptation approach. This strategy increases public safety and is used instead of replacing expensive protection measures over time.

Retreat can be deliberate and managed, or it can occur through abandonment, as an unmanaged, possibly deliberate, ‘letting go’ of a property, structure, or use. Managed retreat can involve relocating a particular piece of infrastructure or land use at risk and moving it to another location on the same property. The ‘abandoned’ land may be left to naturally evolve and find a balanced state (equilibrium); there may also be some interventions to support restoration of natural coastal habitats and ecosystems (salt marsh or dune restoration).

Site-specific, or small-scale retreat can involve public infrastructure (water treatment facilities, roads, public spaces) or private properties (houses, cottages, barns etc.). Retreat can also take place at a larger scale, where entire communities or sections of communities are moved due to future risk of erosion or flooding. This scale of retreat is more challenging since it is often political and requires the agreement of multiple stakeholders. Space (accommodation space) is necessary for retreat to take place, which might not be feasible for some areas.

Table 3.4 ‘Relocate' Strategy Tools

Land Use Planning Tools	Land Use Planning Tools	Regional/rural plan (non-statutory), land use policy
		Integrated community sustainability plan
		Climate change action/adaptation plan
		Shoreline/coastal management plan
		Watershed management plan
		Strategic land acquisition (land bank)
		Wetland policy
	Regulations and Land Use Changes	Wetland regulation
		Statutory community plan
		Zoning
		Setbacks
		Land swap
		Land use conversion and redevelopment
		Land trust
		Rolling easements
		Conservation easements
		Planned retreat
		Abandonment
		Relocate and abandon allowing natural coastal system to re-adjust with minimal intervention

Engineered Coastal Interventions		Relocation with habitat restoration (e.g., salt marsh, dune) and/or soft/hybrid solutions

Example: Le Goulet, New Brunswick

Le Goulet is a coastal fishing community in northeastern New Brunswick. It is located on low-lying and flat terrain, making the community highly vulnerable to rising sea levels, increases in storm surge, and flooding (Figure 1.13). In recent years, the community has been undertaking climate change adaptation planning processes to address these impacts.

Figure 1.13 Dune restoration structure in Le Goulet, NB (Jenna Miller)

First adaptation planning process

The first of three adaptation planning cycles began in 2007, guided by climate change specialists from the University of Moncton.[65] It involved public presentations and focus groups and resulted in the community identifying two main potential adaptation options: voluntary managed retreat accompanied by sand dune restoration and municipal zoning bylaw modifications, or the construction of a 3.8 kilometre long seawall.[66] Though more complicated and controversial among some residents, the option of retreat was seen as more cost-effective and advantageous due to doubts as to the efficacy of a seawall in preventing flooding and contamination of drinking water wells for low-lying homes.[67] Community discussions were also valuable in identifying resources critical for informed decision-making. Immediate needs identified during the deliberations included items such as "(1) the development of a digital elevation risk map that superimposes climate change scenarios (flooding and erosion) with

[65] Richardson, G.R.A (2010). Adapting to Climate Change. An Introduction for Canadian Municipalities. Ottawa, Ontario. Natural Resources Canada. Retrieved 21 December, 2015 from: http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/mun/pdf/mun_e.pdf
[66] Ibid.
[67] Capozi, R. Personal communication, 21 December, 2015, from Aube, M. Institute of Coastal Zone Management, Université de Moncton, Shippagan, Personal communication.

existing topographical features and infrastructure; (2) a modelling study of the impacts of a seawall or dyke on coastal erosion and salt-water intrusion; and (3) a detailed cost analysis for the various adaptation measures."[68] Overall, the university–community partnership successfully initiated an important debate about the future of the community and mobilized its residents.

Innovative zoning by-law

In 2009, as a result of this first adaptation planning cycle, the village's zoning bylaw was modified by the Commission d'aménagement de la Péninsule acadienne (local planning commission) to prevent unsuitable development in a flood-prone areas, where climate change impacts are considered a major risk that developers must consider in their plans.[69,70]

Second adaptation planning process

In 2010, Le Goulet participated in the ACASA-Acadian Peninsula Project in conjunction with the Atlantic Climate Adaptation Solutions Association (ACASA) as a part of the Atlantic Regional Adaptation Collaborative (ARAC) initiative. This project led to the creation of different tools to support decision-makers in dealing with coastal flooding and erosion issues including localized sea level rise and storm surge scenarios,[71] an infrastructure database with risk zones identified based on various erosion and flooding scenarios,[72] an elevation model based on LiDAR data, and maps of flooding and shoreline erosion and accretion (gradual accumulation) scenarios.[73] These tools and maps were then validated and used by different working groups to put together zoning recommendations for the creation of retreat and accommodation zones in 2012[74] and to identify and prioritize risk zones/sectors along with adaptation strategies specific to each.[75]

Dune restoration and beach nourishment

In an effort to protect and restore dunes, structures built from trees, brush, and lobster traps were constructed between 2013 and 2019 over approximately 2 km of Le Goulet's coastline in order to capture wind-blown sand. Beach nourishment was also undertaken in 2013, 2018, and 2019 over more than 1 km of coast, using sediment collected when the local harbour was

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[68] Richardson, G.R.A (2010). Adapting to Climate Change. An Introduction for Canadian Municipalities. Ottawa, Ontario. Natural Resources Canada. Retrieved 21 December, 2015 from: http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/pdf/mun/pdf/mun_e.pdf
[69] Ibid.
[70] Natural Resources Canada; Le Goulet. (2014). Le Goulet's Climate Change Adaptation Plan. Retrieved from: http://www.nrcan.gc.ca/environment/resources/publications/impacts-adaptation/tools-guides/16299
[71] Daigle, R. (2011). Sea-level rise estimates for New-Brunswick municipalities: Le Goulet, Saint John, Richibucto, Sackville, Shippagan, Caraquet. Report prepared for the Atlantic Climate Adaptation Solutions Association. 18pp. Retrieved from: https://atlanticadaptation.ca/en/islandora/object/acasa%3A696
[72] Robichaud, A., Simard, I., Doiron, A., and Chelbi, M. (2011). Infrastructures à risque dans trois municipalités de la Péninsule acadienne. Report prepared for the Atlantic Climate Adaptation Solutions Association. 56pp. Retrieved from: https://adaptationpa.ca/images/PDF_-_Progression/R-Infrastructures_%C3%A0_risque_%C3%A0_Le_Goulet_Shippagan_et_Bas-Caraquet.pdf
[73] Jolicoeur, S. and O'Carroll, S. (2012). Projet de la Péninsule acadienne : Rapport de recherche technique Équipe « Photogrammétrie et cartographie ». Report prepared for the Atlantic Climate Adaptation Solutions Association. 65pp. Retrieved from: https://atlanticadaptation.ca/en/islandora/object/acasa%3A652
[74] Aubé, M. and Kocyla, B. (2012). Adaptation aux changements climatiques : planification de l'utilisation du territoire à Shippagan, Le Goulet et Bas-Caraquet. ACASA-Acadian Peninsula Project. 65pp. Retrieved from: https://adaptationpa.ca/images/PDF_-_Progression/R-Planification_de_lutilisation_du_territoire_%C3%A0_Shippagan_Le_Goulet_et_Bas-Caraquet.pdf
[75] Aubé, M., Hébert, C., and Doiron, A. (2014). Accompagnement de communautés de la Péninsule acadienne dans la planification de l'adaptation aux changements climatiques: année 3. Exercices de planification stratégique à Shippagan, Bas-Caraquet, Le Goulet et Sainte-Marie-Saint-Raphaël, Cap-Bateau et Pigeon Hill. Retrieved from : https://adaptationpa.ca/images/PDF_-_Progression/R-Planification_strat%C3%A9gique_%C3%A0_Shippagan_Bas-Caraquet_Le_Goulet_et_Sainte-Marie-Saint-Rapha%C3%ABl_Cap-Bateau_Pigeon_Hill.pdf

dredged, and dune grasses were planted from 2015-2017 in an effort to help to stabilize the dunes and maintain the sand added through nourishment.[76] The effectiveness of the restoration efforts was monitored annually by Valorēs (known as Coastal Zones Research Institute Inc. prior to 2018) from 2014-2019, with findings demonstrating overall net sediment gain in areas with structures and nourishment compared to net sediment loss in areas without structures.[77] In order to raise local awareness about the dune restoration efforts, a public education campaign was undertaken in 2017.[78]

Third and most recent adaptation planning process

In 2019, an internal committee reviewed the information gathered during the 2013-2014 adaptation planning process as a first step in the creation of a new Climate Change Adaptation Plan.[79] Public consultation was again undertaken through a meeting to discuss the issues, priorities, and actions to be taken in adaptation planning, and opinions garnered through this were integrated into the final plan that was completed in 2020, in the form of four additional new actions. Overall, limited changes were made to the actions that had been previously proposed as residents largely agreed with them.[80]

[76] Aubé, M., Hébert, C., and Jean, S. (2018). Suivi de la restauration des dunes à Le Goulet: année 4. Coastal Zones Research Institute Inc., Projet Adaptation PA. 42pp. Retrieved May 18, 2022 from: https://adaptationpa.ca/images/R-IRZC-2018-Suivi_plage_Le_Goulet_ann%C3%A9e_4.pdf
[77] St-Hilaire, B., Tétégan Simon, M., and Hébert, C. (2020). Suivi de la restauration des dunes à Le Goulet : année 6. Valorēs, Projet Adaptation PA. 41pp. Retrieved May 18, 2022 from: https://adaptationpa.ca/images/PDF_-_Progression/R-IRZC-2020-Suivi_plage_Le_Goulet_ann%C3%A9e_6-VuM.pdf
[78] Aubé, M., Hébert, C., and Jean, S. (2018). Suivi de la restauration des dunes à Le Goulet: année 4. Coastal Zones Research Institute Inc., Projet Adaptation PA. 42pp. Retrieved May 18, 2022 from: https://adaptationpa.ca/images/R-IRZC-2018-Suivi_plage_Le_Goulet_ann%C3%A9e_4.pdf
[79] Cess, M., Pirlet, M., Grandprez, T., and Tétégan Simon, M. (2020). Plan d'adaptation aux changements climatiques du Village de Le Goulet. Valorēs, Projet Adaptation PA. 16 pp. Retrieved from: https://adaptationpa.ca/images/PDF_-_Progression/R-IRZC-Plan_dadaptation_aux_changements_climatiques_Le_Goulet_VF.pdf
[80] Ibid.

3.4 Accommodate ('raise the line')

Accommodate allows for continual use of coastal lands through either changes in the use of the land or changes to existing infrastructure to allow it to co-exist with coastal flooding and/or erosion. 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.

Table 3.5 'Accommodate' Strategy Tool

Land Use Planning Tools	Planning Frameworks	Regional plan (non-statutory), land use policy
		Integrated community sustainability plan
		Climate change action/adaptation plan
		Shoreline/coastal management plan
	Regulations	Statutory community plan
		Tax or development incentive
		Zoning
		Development standards
		Waiver
		Variances
	Site Design	Urban design standards
		Stormwater management
		Coastal development rating system
Engineered Coastal Interventions	Erosion	Artificial reef
		Perched beach (sill)
		Beach nourishment
		Plant stabilization
	Both Flooding and Erosion	Living shoreline/ wetland
		Dune building
	Flooding	Drainage ditch
		Dredging
		Detainment ponds
		Rain garden/ constructed wetland
		Stormwater management
		Wet flood proofing building
		Raised infrastructure
		Floating building

Example: Town of Wolfville, Nova Scotia

In 2021, CBCL Limited completed a Flood Risk Mitigation Plan for the Town of Wolfville. The plan identifies current and future inland and coastal flood risks, including climate change impacts, and evaluates proposed flood risk reduction measures. Inland and coastal flooding in Wolfville can be the result of insufficient capacity of stormwater management infrastructure to runoff during extreme rainfall events as well as extreme coastal water levels (tides and storm surges) causing backup in the stormwater system, overtopping, or reaching inland between or around dykes. Under the RCP8.5 scenario (95th percentile), there is projected to be a 61% increase in the intensity of a 1-in-100-year rainfall event (from 174 mm/hr to 280 mm/hr) as well as a projected increase in peak coastal levels by 1.59m (from 7.76 to 9.35 m CGVD2013; including sea level rise, storm surge, and tidal amplification) by 2100.[81]

In the Flood Risk Mitigation Plan Implementation Plan, CBCL Limited outlines high priority actions recommended to be taken by the Town of Wolfville within 1-5 years. An accommodation adaptation strategy that is contained within these actions is to undertake storm sewer upgrades to 17 pipes, including extending the length of outfalls, in order to increase system capacity. (However, it should be noted that the capacity of the system will remain at zero at high tide.) These capacity increases allow the present stormwater management system to accommodate increased runoff.

Other adaptation actions suggested in the implementation plan that may not fall within the category of "accommodation" strategies include:

- Connecting the two existing dyke systems through design and construction of a new dyke and integrating living shorelines
- Coordinating the raising of existing dykes with the Department of Agriculture
- Raising land around the 6 sewage lift stations (that pump wastewater from lower to higher elevations to the wastewater treatment facility)
- Designing and constructing a new berm around the wastewater treatment facility
- Creating a flood forecasting and warning system in partnership with the Regional Emergency Management Organization
- Community education and communication

[81] CBCL Limited. (2021). Town of Wolfville Flood Risk Mitigation Plan: Final Report. Retrieved from: https://wolfville.ca/component/com_docman/Itemid,264/alias,2864-town-of-wolfville-flood-risk-mitigation-plan-final/category_slug,planning/view,download/

Example: Cheverie, Nova Scotia

Figure 1.14 Cheverie Creek culvert pipe, Cheverie, NS (Tony Bowron, CBWES Inc.)

In 2005, the Cheverie Creek restoration project became the first fully monitored active salt marsh restoration project in Atlantic Canada.[82] In 1960, the tidal flow along Cheverie Creek was significantly restricted by a causeway with a small wooden culvert. The restricted tidal flow ultimately decreased the area of coastal marsh habitat on the landward side of the causeway. Tidal flow was restored by replacing the undersized wooden culvert with a large aluminum culvert (Figure 1.14). CB Wetlands and Environmental Specialists (CBWES Ltd.) and Saint Mary's University designed and monitored the recovery of the salt marsh as a habitat compensation project for the Nova Scotia Department of Transportation and Infrastructure Renewal. Now re-established, the healthy ecosystem has also become a focal point for the local community, engaging local residents, school children, community groups and university students and researchers to build trails, interpretive panels, and a dark chamber to view the marsh.[83]

Salt marshes and their vegetation have been shown to diminish wave energy and height therefore acting as a natural buffer to the impacts of rising sea levels.[84,85] Although the Cheverie project was not initiated specifically as an accommodation adaptation approach, it still addresses the principles of accommodation by increasing the upstream area that could be flooded, therefore decreasing the potential for flooding along the highway (allowing continued use of the highway in its current location). From there, the Cheverie Creek is left to naturally respond to its new conditions (Figure 1.15) while still allowing for people to visit the marsh and for traffic to travel the causeway.


Figure 1.15 Cheverie Creek salt marsh at high tide (1.15a, 2018) and low tide (1.15b, 2021) (Tony Bowron, CBWES Inc.)

[82] Bowron, T. M., Neatt, N., van Proosdij, D., Lundholm, J., and Graham, J. (2011). Macro-Tidal Salt Marsh Ecosystem Response to Culvert Expansion. Restoration Ecology, 19, 307-322.
[83] Ibid.
[84] van Proosdij, D., Graham, J., Bowron, T., Neatt, N., MacIsaac, B., & Wrathall, C. (2014). Development and Application of Managed Realignment to Maximize Ecosystem Services and Climate Change Adaptation. Final report prepared for Environment Canada Gulf of Maine Program. 101 pp.
[85] Bowron, T. M., Neatt, N., van Proosdij, D., Lundholm, J., and Graham, J. (2011). Macro-Tidal Salt Marsh Ecosystem Response to Culvert Expansion. Restoration Ecology, 19, 307-322.

3.5 Protect (‘advance or hold the line’)

Protect 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.

Figure 1.16 Armourstone Revetment in Fundy National Park, NB (Vincent Leys, CBCL Ltd.)

Protection strategies are associated with engineering techniques and are used to manage flooding and erosion within a coastal zone. They can be small-scale, site-specific strategies or large-scale projects used for industry or community protection and management planning. Intervention options include structural or non-structural controls. Examples of protection strategies can be seen in Figure 1.16, Figure 1.17, and Figure 1.18.

Figure 1.17 Beach (foreshore) stabilization in Fortune, NL (Kimberly Bittermann)

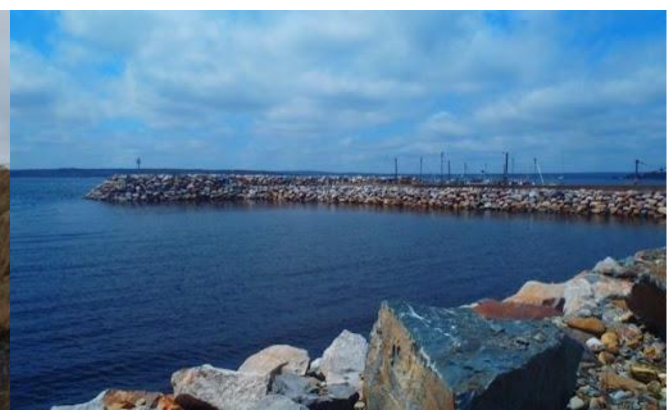

Figure 1.18 First breakwater at Lower Sandy Point, NS (Samantha Page)

Table 3.6 'Protect' Strategy Tools

Land Use Planning Tools	Planning Framework	Regional plan (non- statutory), land use policy
		Integrated community sustainability plan
		Climate change action/adaptation plan
	Regulations	Statutory community plan
Engineered Coastal Interventions	Erosion	Scour Protection
		Engineered Revetment
		Rip-rap Armouring
		Groynes
		Shore-perpendicular breakwater
		Nearshore breakwaters
		Retaining wall
		Artificial reef
		Perched beach (sill)
		Beach nourishment
		Plant stabilization
	Both Flooding and Erosion	Seawall
		Buried revetment
		Living shoreline/ wetland
		Relocate
		Dune building
	Flooding	Dyke
		Rain garden/ constructed wetland
		Stormwater management
		Tide barrier/ aboiteau
		Dry flood proofing building

Coastal protection can involve non-structural (soft) approaches that rely on sustaining natural processes while enhancing coastal resilience with the help of engineering techniques. Such tools include beach nourishment, dune restoration, artificial reefs, wetland (re)creation and other living shoreline techniques. Non-structural protection allows coastal processes to continue, and if designed and implemented well, can help stabilize erosion as well as help protect inland areas from flooding and storm surge.

Soft coastal intervention options are often used in conjunction with structural techniques and are referred to as hybrid techniques. The soft options can provide some protection from negative impacts that could occur if structural techniques were used on their own. For example, a seawall used by itself can cause increased erosion along the edges of the structure as well as increase negative impacts downstream from the site. It should be noted that softer approaches, as with harder approaches, might be more appropriate in some situations than others, depending on risk for the land use being protected or the type of coastal environment. In contrast to the Eastern Seaboard of the USA, very few engineered living shorelines have been implemented in the Atlantic Provinces, and fewer still have a monitoring program associated with them. Demonstration sites being led by NGOs and engineering firms are responding to the increased public interest in more environmentally sustainable solutions to coastal erosion (e.g., CBCL Ltd Consulting Engineers – Mahone Bay, NS).

Example: Tea Hill Park, Stratford, Prince Edward Island

In 2021, four living shoreline demonstration sites were constructed in Prince Edward Island. This was the result of a partnership between the PEI Watershed Alliance (PEIWA), the City of Charlottetown, the Town of Stratford, Creative PEI, and the Mi'kmaq Confederacy of PEI (and other technical support partners) aiming to promote community-based climate action with funding from Environment and Climate Change Canada's (ECCC) Climate Action and Awareness Fund.[86] The new living shorelines are located near the Queen Elizabeth Hospital (QEH) in Charlottetown, on the waterfront in Stratford, at Tea Hill Park in Stratford, and on Lennox Island.

The living shoreline at Tea Hill was designed by CBWES Inc, who also oversaw its implementation. The construction involved the planting of native tree, shrub, and grass species along the bank and the upland path leading down to the beach; as it takes root and grows, this vegetation will help to reduce erosion and to infiltrate runoff from the upland. The beach access path was covered with wood chips to reduce the impact of foot traffic. Haybales and logs were put in place to protect the eroding bank face (Figure 1.19). As this area is a public park without critical infrastructure directly on the coast, it is a great example of a site where softer living shoreline approaches can be utilized; also, the public (and well used) nature of the park area makes it a great demonstration site to introduce living shorelines to the general public.

Figure 1.19 Tea Hill Living Shoreline (PEIWA, Maddy Crowell)

Each of the three living shoreline sites in Charlottetown and Stratford are accompanied by public artworks as a part of the Riverworks initiative by CreativePEI and The River Clyde Pageant.[87,88,89]

[86] City of Charlottetown. (2021). City Completes Living Shoreline Demonstration. Retrieved May 18, 2022 from: https://www.charlottetown.ca/news/current_news/city_completes_living_shoreline_demonstration
[87] CreativePEI. (n.d.). Riverworks. Retrieved May 18, 2022 from: https://creativepei.ca/riverworks/
[88] The River Clyde Pageant. (2022). Riverworks. Retrieved May 18, 2022 from: https://www.riverclydepageant.com/riverworks
[89] CBC News. (2021). New shoreline installations in Stratford raise awareness about erosion and climate change. Retrieved May 18, 2022 from: https://www.cbc.ca/news/canada/prince-edward-island/pei-shoreline-installations-stratford-climate-change-1.6111485

Example: Town of Ferryland, Newfoundland and Labrador

Coastal geomorphologist Dr. Norm Catto of Memorial University of Newfoundland conducted a coastal vulnerability assessment calculating Coastal Erosion, Sensitivity and Petroleum Vulnerability indexes for the north, south, head and beach extents of the Ferryland, NL shoreline. The work was a project of the Atlantic Climate Adaptation Solutions Association (ACASA), completed in 2013.[90]

The study concluded that the beach and tombolo portion of Ferryland was the most vulnerable to coastal erosion due to its exposure to high wave and storm activity. Through the combination of seawalls and riprap (Figure 1.20) the exposure to wave energy present within this area was reduced, which ultimately protects key infrastructure such as roads for the town. Consequences of using such protection structures were observed, such as obstructions and alterations in sediment flow resulting in loss of beach slope, and areas with no seawall and riprap protection experienced accretion, erosion, and over-wash. Therefore, in the absence of protection structures, this particular section of Ferryland is even more vulnerable to these forces, which in turn can increase risk to houses and local roads.[91] Due to the high energy and exposure of this site to waves as well as the critical nature of the infrastructure being protected, softer approaches such as living shorelines would be less appropriate than the harder measures used here.

Figure 1.20 Riprap implemented in October 2011 along the west section of the Eastern Ferryland Beach, Newfoundland and Labrador (Catto[1])

[90] Catto, N. (2012). Coastal Erosion in Newfoundland: Town of Ferryland Community Report. Report submitted to the Atlantic Climate Adaptation Solutions Association (ACASA), March 2012, 12 pp.
[91] Ibid.

3.6 Maladaptation

Even when hard structures are built with the best intentions to protect the coast and prevent or slow erosion (particularly shore-parallel structures e.g., dykes, riprap revetments), they still play an important role in the degradation of those coastal features and ecosystems that act as natural adaptive tools (e.g., dunes, salt marshes). Furthermore, there is a perception that protection structures provide an additional level of safety that is not readily associated with other adaptation options. This perception can result in a false sense of security among residents that live adjacent to protection structures, especially with the increase in future sea level rise and storm surge events. This increased perception of safety has led to increased development behind protective structures in some locations. For example, the town of Truro, NS is located where the Salmon River flows into the Cobequid Bay, at the easternmost part of the Minas Basin, Bay of Fundy. The Town relies heavily on the maintenance of dykes and is often at risk of flooding during seasonal storms.

When an adaptive measure unintentionally ends up causing harm rather than good, it is termed “maladaptation”. As the roles of hard built structures and coastal squeeze have become better known, efforts have been made to reduce their negative impact and reduce maladaptation through “soft” or “hybrid” measures (Figure 1.21).

The positive role that natural systems such as dunes and salt marshes can play in adaptation has also been increasingly recognized, and efforts to restore them have increased in recent years as well as the use of “living shorelines” and other “nature-based approaches” (soft measures) as options to replace hard built structures. For example, salt marsh restoration and managed realignment (Figure 1.22) are being undertaken as viable adaptation measures and proving to be effective (e.g., in the dyked areas around the Bay of Fundy). However, overall, the best adaptation option in response to climate impacts on the coast in all areas is managed retreat or relocation when possible; this is inevitable in many places and can be more cost-effective in the long-term than constant maintenance and upgrading of coastal protective structures and the costs of repairing damage after storms.[92,93,94,95,96,97]

[92] Dietz, S. and Arnold, S. (2021). Atlantic Provinces; Chapter 1 in *Canada in a Changing Climate: Regional Perspectives Report*, (ed.) F.J. Warren, N. Lulham and D.S. Lemmen; Government of Canada, Ottawa, Ontario.

[93] van Proosdij, D; Manuel, P.; Sherren, K.; Rapaport, E; McFadden, C.; Rahman, T.; & Reeves, Y. (2021). Making room for movement: A framework for implementing nature-based coastal adaptation strategies in Nova Scotia. TransCoastal Adaptations Centre for Nature-based Solutions, Saint Mary’s University. Prepared for Natural Resources Canada.

[94] Lodder, Q., Jeuken, C., Reinen-Hamill, R., Burns, O., Ramsdell, R. III, de Vries, J., McFall, B., IJff, S., Maglio, C., and Wilmink, R. (2021). “Chapter 9: Beaches and Dunes.” In Natural and Nature-Based Features Guidelines. Edited by T. S. Bridges, J. K. King, J. D. Simm, M. W. Beck, G. Collins, Q. Lodder, and R. K. Mohan. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

[95] Piercy, C. D., Pontee, N., Narayan, S., Davis, J., and Meckley, T. (2021). “Chapter 10: Coastal Wetlands and Tidal Flats.” In International Guidelines on Natural and Nature-Based Features for Flood Risk Management. Edited by T. S. Bridges, J. K. King, J. D. Simm, M. W. Beck, G. Collins, Q. Lodder, and R. K. Mohan. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

[96] Torio, D.D., and Chmura, G.L. (2013). Assessing coastal squeeze of tidal wetlands. Journal of Coastal Research, 29 (5), p. 1049-1061.

[97] Doody, J. (2013). Coastal Squeeze and Managed Realignment in Southeast England, does it tell us anything about the future? Ocean & Coastal Management, 79, 34-41.

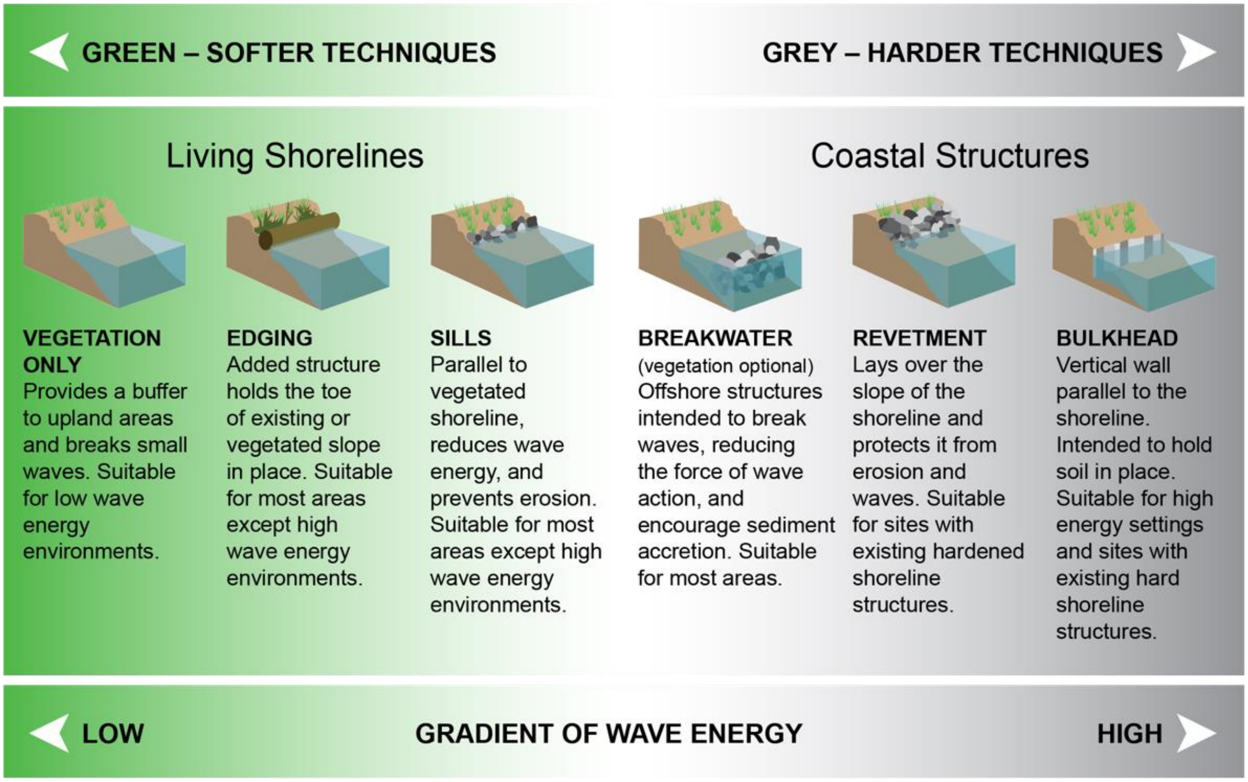

Figure 1.21 Continuum of green (soft) to gray (hard) shoreline protection techniques (modified from Guidance for Considering the Use of Living Shorelines, NOAA[98])

Figure 1.22 Managed Realignment as Managed Retreat: Converse, NS, July 25, 2021, 3 years post realignment (TransCoastal Adaptations Centre for Nature-Based Solutions)

[98] NOAA (2015). Guidance for Considering the Use of living shorelines. Retrieved from: http://www.habitat.noaa.gov/pdf/noaa_guidance_for_considering_the_use_of_living_shorelines_2015.pdf after Sage, 2015 Natural and Structural Measures for Shoreline Stabilization pdf brochure at http://sagecoast.org/docs/SAGE_LivingShorelineBrochure_Print.pdf

Chapter 4: Adaptation Approaches – Making a Suitable Choice

There are a number of factors to consider when making a suitable adaptation choice. Not every strategy is appropriate for a particular location or community. Table 4.1 lists factors that can influence the suitability of coastal adaptation options. The questions are answered throughout the different steps of adaptation planning and provide a starting point for communities to begin planning for their particular coastal conditions.

Table 4.1 Factors that influence the suitability of coastal adaptation options

Suitability of Coastal Adaptation Options	
Coastal Hazard	What is happening?
Geographic and Environmental Setting	Where is it occurring?
Scale	Site specific local or regional issues?
Local Capacity	What resources and skills do you have at your disposal to aid in addressing this issue?
Local Planning Objectives	Is there a set of goals you wish to address when dealing with this issue?
Planning Horizon	Are you looking at a long-term or short-term goal? How urgent is the issue?

The suitability of adaptation options can be influenced by what is happening at the coast – the coastal hazard, coastal setting, the time frame of the changes, the size of the area affected, local capacity to address coastal issues, local planning objectives and the planning horizon for making change. It is important to identify an adaptation strategy and tools that are suited for addressing the problem.

However, simply addressing these factors does not mean that adaptation will be successful. There are other requirements for effective adaptation. The success of an adaptation strategy will also depend on its ability to reduce vulnerability to a particular coastal hazard in a cost-efficient way, as well as adding economic, environmental, or social benefits to the community or landowner.[99] Adaptation success is challenging to define, as there are many factors that influence it. Success must be considered in terms of its current and future effectiveness. Future effectiveness must be assessed based on a changing environment, making it complicated to define. Future climate change scenarios have a level of uncertainty that makes an evaluation of future success difficult.[100] Table 4.2 presents a number of processes that lead to good adaptation, derived from a number of international and national adaptation guidance reports.

It is not always possible to incorporate all of the principles in Table 4.2. When attempting to prioritize adaptation planning, conflicting socio-cultural, economic, and political views can complicate decision-making. This checklist can guide what to look for, however, when practicing

[99] Brown, A., Gawith, M., Lonsdale, K., and Pringle, P. (2011). *Managing adaptation: linking theory and practice.* UK Climate Impacts Programme, Oxford, UK.

[100] Moser, S., and Boykoff, M. (Eds.). (2013). *Successful Adaptation to Climate Change: Linking Science and Policy in a Rapidly Changing World.* New York, NY: Routledge.

adaptation planning. The key point is to focus objectives and arrive at a decision that provides the most beneficial, low risk option for a community. By using these guiding principles, a community is less likely to use unsuitable options that do not provide the adequate or appropriate responses that could lead to increased future vulnerability.[101,102]

Table 4.2 Principles that lead to effective adaptation

Knowledge Building • Collecting data and monitoring of technical and quantitative impacts related to coastal hazards, scenario planning and vulnerability assessments. • Integrating local skills as well as training and development of new skills within the community. • Establishing partnerships to ensure that decisions are made by a well-informed audience. • Changing or developing regulations, standards, codes, plans, policies, or programs. • Promoting awareness of climate related issues.
Environmental and Social Justice • Supporting the use of natural ecosystem functions as a way of protection from future coastal hazards. • Avoiding actions that lead to the displacement of impacts onto another area. • Incorporating the social characteristics, beliefs, and values of communities into adaptation planning considerations. • Supporting the diversification of land use and economic activities. • Increasing incentives for the community to take part in adaptation practices. • Ensuring adaptation action does not increase inequalities within the community but that they promote equitable initiatives.
Focus • Understanding risks and focusing action to manage priorities. • Focusing on specific objectives that are achievable within a specific timeframe. For example, the UK Climate Impacts Programme (UKCIP) SMART objectives stand for Specific, Measurable, Achievable, Result-oriented, and Time-bound objectives.
Flexibility • Integrating uncertainties of climate related risks and changes. • Avoiding action that limits adaptation in the future which can ultimately be irreversible if issues arise. • Taking into account conflicts between strategies. • Promoting actions that benefit both climate and non-climate components of coastal adaptation.
Sustainability • Ensuring that the adaptation measures reduce vulnerability for years to come.

[101] Barnett, J., and O'Neill, S. (2010). Maladaptation. *Global Environmental Change—Human and Policy Dimensions, 20*, 211-213.
[102] Moser, S., and Boykoff, M. (Eds.). (2013). *Successful Adaptation to Climate Change: Linking Science and Policy in a Rapidly Changing World.* New York, NY: Routledge.

4.1 How prepared is your community?

A community's ability to cope with change depends on the availability of resources. Resources can mean a variety of services, ranging from social cohesion, workforce availability and skills, to environmental conditions and existing partnerships. Resources that influence a community's ability to adapt are described in more detail in Table 4.3. In general, the more resources available, the greater the likelihood a community will be able to adapt to coastal hazards.

Table 4.3 Resources that influence a community's ability to cope with coastal hazards[103,104]

Human Resources • A community benefits from a population with diverse skilled workers. • The political will of a community depends on individual perceptions and attitudes towards coastal hazards and what should be done to lessen the impacts. • Indigenous Traditional Knowledge can support a community.
Social Resources • The willingness of community members to work together improves their ability to cope with climate change. • In a community with strong leadership, a sense of community, and safety nets in place, there will be a greater emphasis to establish community strategies to help lessen the impacts of climate change on their coast.
Institutional Resources • Collaborating with organizations and universities can form a mutually beneficial relationship and increase awareness of coastal adaptation for the community. • Such relationships can help communities choose adaptation solutions through capacity building tools.
Natural Resources • What are the conditions of the environment? • Areas that are less built up by human infrastructure have a greater ability to absorb changes from coastal flooding and erosion. • Local availability of building materials.
Technological Resources • Capacity to cope with flooding and erosion from climate change can increase with the help of certain technologies. • These include programs to assess coastal vulnerability, training in coastal management, and emergency and land use planning.
Financial Resources • Financial investment in proactive coastal management strategies will allow for less strain on the community's finances if issues arise due to a storm event. • Financial support may also lead to increased investment commitments for community planning related to future sea level rise.

[103] Wall, E., and Marzall, K. (2006). Adaptive Capacity for Climate Change in Canadian Rural Communities. *Local Environment, 11 (4)*, 373-397.
[104] Dolan, A., and Walker, I. (2004). Understanding Vulnerability of Coastal Communities to Climate Change Related Risks. *Journal of Coastal Research, Special Issues 39*, 1317-1324.

If a community does not have adequate capacity to deal with climate change issues, their ability to adapt will be limited. Therefore, it is important for communities to use capacity building tools (Table 4.4) to increase resilience for the future. The majority of the capacity building tools are suitable for all phases of adaptation planning (Figure 1.24). They are widely used in land use planning and are tools that encourage strong engagement between coastal users and help to foster community responsibility. There is some overlap between capacity building tools and the knowledge building section of Table 4.2, emphasizing their importance as initial steps towards informed and effective adaptation planning.

Table 4.4 Land use planning capacity building tools

Capacity Building Tools
Partnerships
Local committees
Education
Community engagement
Community asset mapping
Vulnerability assessment
Scenario planning
Data gathering and mapping
Monitoring
Visioning and public consultation

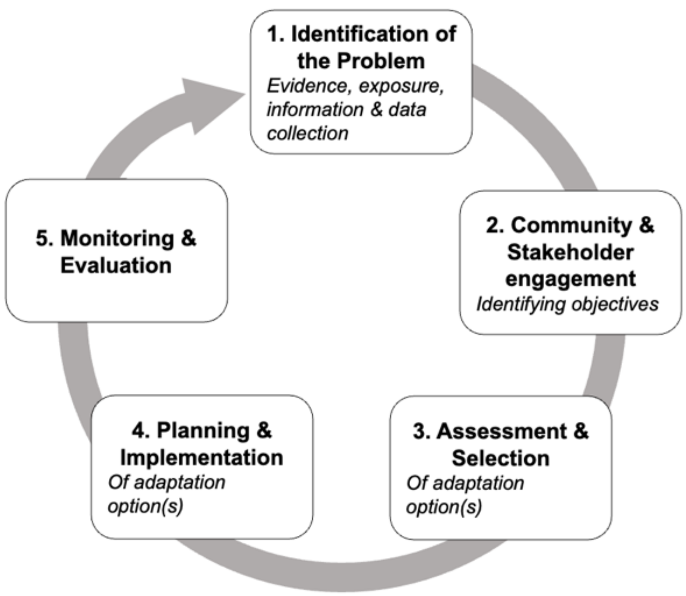

Figure 1.24 Steps towards adaptation[105,106,107]

[105] Arlington Group. (2013). Sea Level Rise Adaptation Primer: A toolkit to build adaptive capacity on Canada's South Coasts. Report prepared for British Columbia Ministry of Environment, 150 pp.
[106] Brown, A., Gawith, M., Lonsdale, K., and Pringle, P. (2011). *Managing adaptation: linking theory and practice*. UK Climate Impacts Programme, Oxford, UK.
[107] Bowron, B., & Davidson, G. (2011). *Climate change adaptation planning: A handbook for small Canadian communities*. Report prepared for the Canadian Institute of Planners, 59 pp.

4.2 Step by step guide to making adaptation choices

The procedure a community chooses will be unique to their particular needs and have objectives influenced by available resources.

STEP 1. Identification of the problem: providing evidence, exposure information, and data collection

Prior to developing and implementing an adaptation plan, a community needs to gather information about its physical and social and cultural setting, as well as about Indigenous rights and traditions in the area. This information can provide evidence of vulnerable areas and other risks associated with present and future climate conditions: it describes exposure to hazard and risk.

Inquiries

- Is there sea level rise data available for my community/region?
- Has there been any research done in the past that deals with coastal flooding or erosion?
- Can I access this information?
- Do residents have photos or stories of changing local environment?

Data gathering involves both scientific and social research, identifying the knowledge gaps that explain the human environment (e.g., social, economic and political processes) and the natural environment (e.g., biological and physical coastal processes). Tide and flood data along with locally relevant sea level rise projections can help determine future areas at risk. Vulnerability assessments can also look at spaces and places that are socially and culturally important to the community. Impacts to Indigenous rights and traditions also need to be assessed. Gathering this information is an important part of determining most appropriate options along a particular coastline.

There are many studies available to Atlantic Canadians that explain work in the region to identify coastal climate change vulnerabilities. Work previously completed through the Atlantic Climate Adaptation Solutions Association (ACASA) provides examples and information about sea level rise that communities can use to assess their unique situations regarding climate change impacts. These and other related resources are now available through CLIMAtlantic, the climate services hub for the Atlantic provinces (www.climatlantic.ca).[108] There are also provincial guidance documents to help communities organize data collection and assessments and integrate the information into the planning process. Examples include the *7 Steps to Assess Climate Vulnerability in Your Community*[109] (a toolkit for Newfoundland and Labrador) and

Research is usually completed by government agencies, local environmental groups and non-governmental organizations, and educational facilities (elementary and high schools, colleges and universities). Begin asking local representatives and residents if they know of any research that already exists. Get in contact with the partners involved in the project to get more information.

[108] CLIMAtlantic resources are available through the website https://climatlantic.ca/

[109] Newfoundland and Labrador Department of Environment and Conservation. (2012). 7 Steps to Assess Climate Vulnerability in Your Community. Natural Resources Canada. 346 pp.

Climate Change Adaptation: A Toolkit: Sackville, Port Elgin, Dorchester and Memramcook.[110] By using the information gathering and assessment techniques described in these resources, community decision-makers will have a clearer sense of what the problems are, how they will change the environment and what impacts they will have on property, infrastructure, and buildings, as well as the overall risks to the community.

Climate Change Adaptation Toolkit: Sackville, Port Elgin, Dorchester, Memramcook, NB

Due to its low-lying geography, the Tantramar region is vulnerable to flooding and sea level rise. It is the only land access between Nova Scotia and the rest of Canada, making it economically important for New Brunswick and Nova Scotia.

EOS Eco-Energy created the *Tantramar Region Toolkit* in 2013 for citizens of the area to better understand climate change as it relates to their local environment and experience. Both the NB Environmental Trust Fund and the NB Regional Adaptation Collaborative funded the project.

Features

- Local research examples
- Historic storm events
- Suggestions for residents and municipal representatives
- Plenty of diagrams and photos
- Resource lists and contact information for additional support.

(*Note: this toolkit has not been updated since its 2013 publication*)

[110] Marlin, A. (2013). Climate Change Adaptation: A Toolkit: Sackville, Port Elgin, Dorchester, Memramcook. EOS Eco-Energy Inc, 40 pp.

STEP 2. Community and stakeholder engagement: identifying objectives

Once coastal climate change impact information has been gathered, community stakeholders and decision-makers should use the research and results to come up with clear objectives for future planning. For the public to become engaged, citizens need to understand the future risks to their community. Providing the information to the public through public education workshops (Figure 1.25), bulletins and radio/television information sessions can help generate involvement in future decision-making. Making information about coastal risks publicly available, including how decisions will be made, can help garner necessary public feedback and support. Ultimately, the public will play a role in determining the objectives of the local adaptation planning process.

Figure 1.25 Citizens and representatives taking part in a public workshop prior to the Jijuktu'kwejk (Cornwallis River) Belcher St realignment (TransCoastal Adaptations Centre for Nature-Based Solutions)

The public's attitudes toward how much risk is acceptable to the community will influence the timing and the type of tools that a community will use. The public's opinion on what are considered valuable assets to the community also influences what coastal areas become prioritized. Another influential factor is how the community will financially support the proposed plan. Small communities often have very limited financial resources; supporting a climate adaptation plan may lead to cuts in other areas of the community's budget. All of these issues will arise during community engagement and will be challenging to address, but they are important to resolve so that adaptation is supporting the community's best interests.

Inquiries

- Does your local government or environmental/community organization(s) keep the public informed on coastal related issues?
- Is there a space where the public can express their ideas and concerns?

Consider opportunities

- for dialogue on adaptation options
- to help the community.

Steady dialogue between government, organizations and the public leads to a positive relationship. Community members should feel well-informed on the potential impacts of climate change on their property and well-being. Providing a space for people to express ideas and opportunities as well as concerns strengthens a community's capacity to deal with climate change.

STEP 3. Assessment and selection of adaptation option(s)

Decision-makers can identify a range of adaptation options that would be appropriate for dealing with risks. These options can then be prioritized according to how well they fit into the objectives established by the community. The assessment typically includes an evaluation of how successful an adaptation option can be at solving a community's problem. As discussed previously, success is determined by how effective and efficient the adaptation option is at reducing vulnerability to a particular risk or hazard. Success is not only determined by whether or not it does what it says it will, but also its ability to be effective with the most benefits for the economic, social, and natural environment.[111]

The selection of an appropriate adaptation option takes time. Stakeholder participation and public inquiries are necessary to make sure there is no conflict between coastal users once the decision is made. The selection committee should understand that the type of coastal environment is an important factor when selecting an appropriate adaptation option.

Table 4.5 lists additional criteria that should be considered when selecting adaptation options, including how flexible, practical, politically, or culturally legitimate and robust the adaptation options can be. Table 4.6 shows economic assessments that are available to support choosing the preferred option.

Table 4.5 Criteria used in assessments to select suitable adaptation options

Efficiency • Are objectives achieved in a well-organized manner with minimal use of available resources?
Equity • Will the option benefit the majority of groups within the community?
Effectiveness • Will the option meet specified objectives?
Urgency • How immediate is the exposure and how great the risk of impact? How critical is the infrastructure?
Practicality • How sustainable is the option? • How difficult will the option be to implement? • Can the option be implemented in a suitable time period? • Are required materials or resources locally available?
Feasibility • Is the intended option affordable?
Legitimacy • Does it have political and cultural acceptability?
Robustness • Is the option effective for a broad range of future impacts?

[111] Brown, A., Gawith, M., Lonsdale, K., and Pringle, P. (2011). Managing adaptation: linking theory and practice. UK Climate Impacts Programme, Oxford, UK.

Flexibility
• Can the option be adjusted for future changes?

Table 4.6 Economic assessment strategies to help select adaptation options[112,113,114]

Cost-Benefit Analysis (CBA)
• Do the benefits outweigh the costs of the option? • Costs refer to direct and indirect monetary costs associated with implementing the adaptation option. • The benefits can be environmental, social, and economic. • The CBA makes it possible to compare a variety of categories or criteria all at once and merge differing criteria into a single value.
Cost-Effectiveness Analysis (CEA)
• What options achieve an objective in the most cost-efficient way? • Can be used when benefits cannot be assigned monetary value. • Used to determine the lowest-cost option that still meets the main objectives of adaptation. • The time frame or cost of implementing strategic land use plans vary substantially depending on available resources.
Multi-Criteria Analysis (MCA)
• When there are a number of benefits that cannot be grouped, multi-criteria analysis can be used in order to rank and prioritize the criteria. • Weighing scheme is created using stakeholder input.
Avoided Costs Calculation
• Estimation of the monetary value that an adaptation option offers. • The difference between projected costs due to hazards (e.g., flooding, erosion) with or without adaptation, relative to a baseline over a specified time period. • Cost outputs in "present monetary value" with adaptation costs discounted annually at a specified rate (e.g., 3%) over the time period. • Discounting into the future accounts for the tendency to value $1 today more than $1 in the future.

[112] Modified from UNFCCC. (2011). Assessing the Costs and Benefits of Adaptation Options: An Overview of Approaches. Report prepared by the United Nations Framework Convention on Climate Change as part of The Nairobi Work Programme on impacts, vulnerability and adaptation to climate change. 52 pp.
[113] MNAI. (2021). Managing Natural Assets to Increase Coastal Resilience, Guidance Document for Municipalities. Retrieved from https://mnai.ca/media/2021/11/MNAI-Coastal-Asset-Guidance-Doc-cover-101-combined.pdf
[114] Bridges, T. S., King, J. K., Simm, J. D., Beck, M. W., Collins, G., Lodder, Q., and Mohan, R. K. (Eds.). (2021). International Guidelines on Natural and Nature-Based Features for Flood Risk Management. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

STEP 4. Planning and implementation of adaptation option(s)

An appropriate adaptation option can be chosen once sufficient information is gathered from the risk assessment to make a decision. A procedure for implementing the adaptation option will identify the roles and responsibilities of those involved and will keep the work on schedule. The implementation procedure should be flexible enough to allow for unexpected delays or changes that may improve the effectiveness of the option being implemented.

When planning the implementation of adaptation options, it is important that objectives be clearly laid out so that all project leads, partners, and stakeholders can understand and agree on performance metrics for the option being implemented. This allows for later monitoring and evaluation to remain unbiased when there are multiple groups involved in order to avoid potential conflicts or barriers in the success of a project. Set objectives should be realistic and SMART (specific, measurable, achievable, relevant, and time-bound).[115]

Steps toward Planning and Implementation:

- Establish main priority actions.
- Create a procedure on how to establish priorities.
- Create a time frame and schedule with milestones to complete.
- Assign different phases of the implementation process to project leads.
- Allow for sufficient time for training and outreach to take place.
- Communicate the steps of the implementation plan to stakeholders and communities.

It is important to determine who is responsible for monitoring and evaluation and incorporate that information into the implementation plan. Quite often monitoring of the project does not occur because the funding was not set-aside at the beginning of the project.

[115] de Looff, H., Welp, T., Snider, N., and Wilmink, R. (2021). "Chapter 7: Adaptive Management." In *International Guidelines on Natural and Nature-Based Features for Flood Risk Management*. Edited by T. S. Bridges, J. K. King, J. D. Simm, M. W. Beck, G. Collins, Q. Lodder, and R. K. Mohan. Vicksburg, MS: U.S. Army Engineer Research and Development Center. 48 pp.

STEP 5. Monitoring and evaluation

Once an adaptation option is in place, monitoring adaptation progress will determine if the option is working as intended. Evaluation should reflect the performance metrics laid out in the planning stage. Effectiveness is measured by how the option was able to solve the problem and how much of the problem has been solved. If there are still unresolved problems, the monitoring process determines the remaining issues and how to change the strategy or tools to address them. Changing, or adapting, the strategies or tools undertaken in a project to accommodate changes in the system is a part of *adaptive management*, which is a structured and repetitive method of decision-making used to reduce uncertainty over time.

In adaptive management processes, ongoing monitoring, data collection, and observation are used to learn from system response to the measure initially implemented. This allows decision-making to meet set objectives while also accumulating the information and knowledge needed to improve future management and decision-making practices and policies. Adaptive management is key in the planning, monitoring, and evaluation phases of coastal adaptation due to the uncertain nature of how the ecosystem will respond to climate change impacts.[116,117]

The time frame of when an option should be reviewed depends on the adaptation option chosen. For example, some land use planning options take a long time to be implemented; therefore, evaluation may span 10 to 30 years. An adaptation strategy such as raising a waterfront could be monitored and evaluated for its effectiveness during the next major storm event which could be weeks, months or even years away from completion of the project.

Example: Adaptive Management Within the Belcher Street Marsh Dyke Realignment and Tidal Wetland Restoration Project[118,119]

In 2017, the Nova Scotia Department of Agriculture commissioned CBWES Inc. to develop a managed dyke realignment and tidal wetland restoration plan for the Belcher Street marsh on the Jijuktu'kwejk (Cornwallis) River in Kentville, Nova Scotia. This project is a part of the *Making Room for Wetlands* project being undertaken by TransCoastal Adaptations: Centre for Nature-Based Solutions at Saint Mary's University with funding from the Department of Fisheries and Oceans. In 2018, the dyke was breached in order to re-align it (managed realignment), after baseline monitoring and restoration designs were complete.

While a site is adjusting to the reintroduction of tidal flooding and finding a new equilibrium, some areas may not respond as was initially anticipated. In 2019, site monitoring post-restoration led to the identification of two areas where recovery was not occurring as desired. This posed a risk to the stability of the dyke and to foreshore marsh recovery.

Successful adaptive management techniques were implemented in both areas in response to this risk, including:

[116] Ibid.
[117] van Proosdij, D., Manuel, P., Sherren, K., Rapaport, E, McFadden, C., Rahman, T., and Reeves, Y. (2021). *Making room for movement: A framework for implementing nature-based coastal adaptation strategies in Nova Scotia.* TransCoastal Adaptations Centre for Nature-based Solutions, Saint Mary's University. Prepared for Natural Resources Canada. 77 pp.
[118] Ibid.
[119] Manuel, P., Rapaport, E., Ewashen, N., Kowal, C., and Warren, K. (2021). Belcher Street Marsh Dyke Realignment and Tidal Wetland Restoration Project: A Case Study of Nature-based Coastal Adaptation in Nova Scotia. School of Planning, Dalhousie University. 37 pp.

- The hand-digging of a channel connecting water that was ponding at the foot of the dyke with a larger drainage network located at the back of the site; this led to the improvement of re-vegetation and soil stability as well as the reduction of the amount of water that was trapped so that by 2021, plants grew in the area and it was nearly revegetated and thus nearly indistinguishable from the marsh surrounding it (Figure 1.26).
- Adjustments were made to reduce the speed of water flowing across the living shoreline and to increase sediment buildup on the marsh surface where scour was occurring (plants were being removed by wave action). Vegetation was planted to fill gaps in rooted areas, and woven wood fencing and brush mats were combined with transplanted marsh vegetation to encourage vegetation recovery. By 2021, though a small amount of drainage was still occurring, it did not appear to pose a risk, and vegetation cover was increasing.

Figure 1.26 Adaptive management practices being undertaken at the Belcher St realignment site, 2019 (1.26a left: runnels being dug by hand; 1.26b right: living shoreline repair; TransCoastal Adaptations Centre for Nature-Based Solutions)

Chapter 5: Coastal Systems and Compatibility of Adaptation Options

An understanding of coastal environments is key to choosing the best adaptation approach. This section describes the coastal systems of the Atlantic Provinces and the most appropriate management strategy for each coastal system (estuary, sandy beach, cliff etc.).

5.1 Estuaries

An estuary is where a river enters the ocean: fresh and saltwater mix and the river is tidal in its lower reach (Figure 1.27). The environment is low-lying, consisting of a mixture of sandy and muddy sediments (e.g., sand, silt, and clay) that are transported by the river, tides, waves, and ocean currents and that build up along the shoreline over time (Figure 1.28).[120] Ports, towns, and cities have historically developed along estuaries to take advantage of easy access to both river and ocean transportation, for access to natural resources and to use the river and tidal flow for waste management.[121]

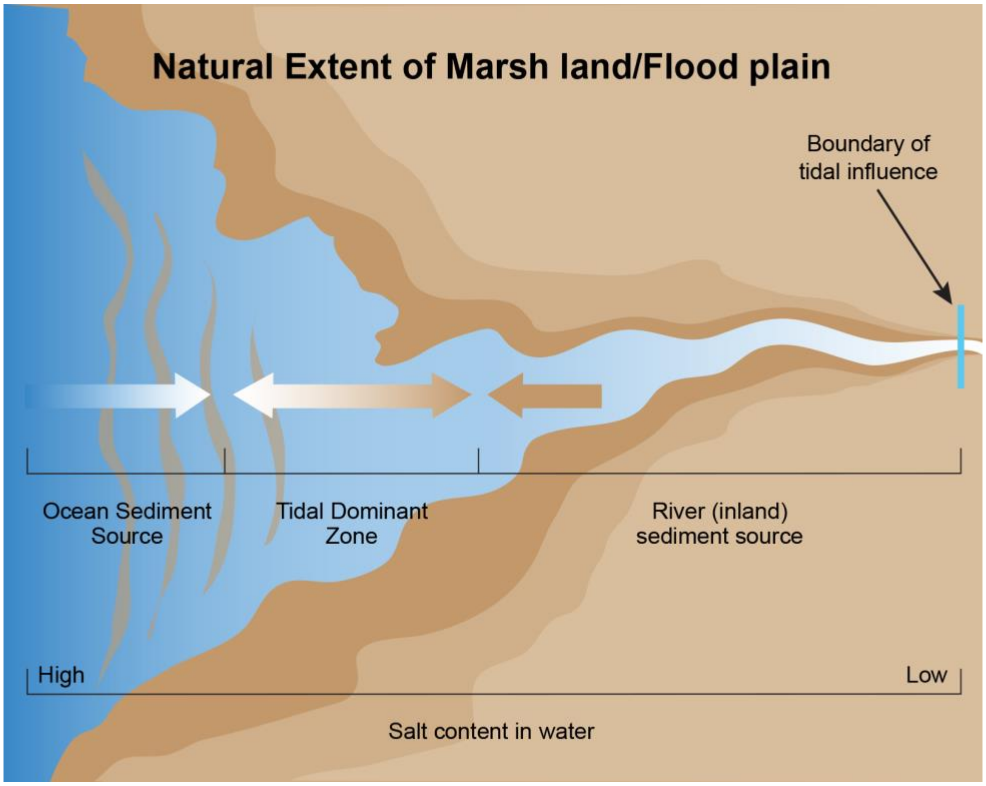

Figure 1.27 Processes within an estuarine system (modified from Dalrymple[122])

[120] Bird, E. (2001). *Coastal Geomorphology: An Introduction.* New York: John Wiley & Sons Inc.
[121] Prandle, D. (2009). Introduction. In *Estuaries: Dynamics, Mixing, Sedimentation and Morphology* (Ch. 1, pp. 1-22). New York: Cambridge University Press.
[122] Dalrymple, R. W., Zaitlin, B.A., and Boyd, R. (1992). A conceptual model of estuarine sedimentation. *Journal of Sedimentary Petrology, 62*, 1130-1146.

Figure 1.28 Point Wolfe River estuary at high (1.28a), and low (1.28b) tide, Fundy National Park, NB (Jenna Miller)

The main impacts of climate change on the shorelines of estuaries will be the result of relative sea level rise (RSLR). RSLR will increase the mean water level in estuaries, as sea level is the main control of estuarine water level; this could lead to saltwater reaching further upriver, increasing the relative height and location of the boundary of tidal influence. Higher water levels could lead to an increase in wave heights and storm surge flooding as well as an increase in the rate of erosion.[123] In order to adapt to these impacts, managed realignment of hard infrastructure such as dykes could be implemented to allow room for the natural expansion and inland migration of the estuarine environment. Managed retreat could also be implemented to move critical infrastructure out of flood plains as these increase in size/height.

[123] Glamore, W. C., Rayner, D. S., and Rahman, P. F. (2016). Estuaries and climate change. Technical Monograph prepared for the National Climate Change Adaptation Research Facility. Water Research Laboratory of the School of Civil and Environmental Engineering, UNSW.

Table 5.1 Factors and concerns for management options for estuaries[124,125,126,127,128]

Driving Factors	• Tides and waves control sediment movement and channel formation. • Freshwater discharge controls the pattern/location of sediment accumulation. This zone of settling is referred to as the turbidity maximum and occurs where the fresh and saltwater meet.
Impact Concerns	• Flooding concerns in low-lying environments such as estuaries, which are highly vulnerable. • Sea level rise increases flooding, extent and depth, in already vulnerable areas. • Storm surge reaches higher levels of land and increases intensity with rising sea levels.
Management Options	• Recommended options include restoration of salt marshes, oyster reefs, managed realignment of coastal defenses, and managed retreat. • Hard shore protection options should only be used in situations such as working waterfronts where relocation is not practical. • Other approaches include the use of flood hazard mapping, coastal setbacks, establishment of flood warning systems, and the flood proofing of buildings.

[124] Bird, E. (2001). *Coastal Geomorphology: An Introduction.* New York: John Wiley & Sons Inc.
[125] Davidson-Arnott, R., Bauer, B., and Houser, C. (2019). *Introduction to Coastal Processes and Geomorphology, Second Edition.* Cambridge University Press.
[126] Jordan, C. J. (Ed.). (2012). *Estuaries: Classification, Ecology and Human Impacts.* New York: Nova Science Publishers Inc
[127] Linham, M. M., & Nicholls, R. J. (2010). *Technologies for Climate Change Adaptation: Coastal Erosion and Flooding.* UNEP Risø Centre on Energy, Climate and Sustainable Development, 166 pp.
[128] van Proosdij, D., & Page, S. (2012). *Best Management Practices for Climate Change Adaptation in Dykelands: Recommendations for Fundy ACAS sites.* Report submitted to the Atlantic Climate Adaptation Solutions Association (ACASA), September 2012, 149 pp.

4.1 Coastal sandy systems

The coastal sandy system is an integrated system encompassing beach, dune, and back barrier environments (Figure 1.29 and 1.30). Some coastal sandy systems also have lagoons. Some beaches may be fully or partially separated from the main coast and are referred to as barrier islands or spits. Coastal sandy systems are highly dynamic and vary in how they respond to wave and tidal conditions.[129]

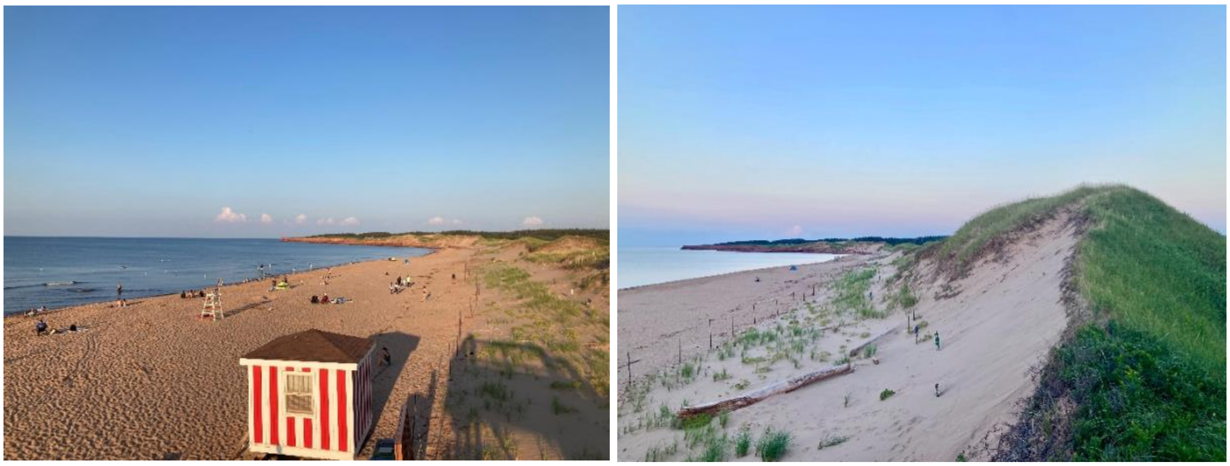

Figure 1.29 Beach (1.29a) and dune system (1.29b) at Cavendish Beach, Prince Edward Island National Park (Jenna Miller)

Coastal sandy systems change seasonally both in shape and composition of the beach (e.g., sand to cobble). Sand is stored in nearshore bars during the fall and winter months, often revealing an underlying layer of gravel or cobbles. The sand stored in the nearshore bars is gradually transported back to the beach during calmer wave conditions over the spring and summer months. These two conditions are referred to as a summer beach profile and a winter beach profile. These beaches result from a dynamic equilibrium or balance of sediment erosion, transport, and deposition. Sand may also move along the shore (alongshore), just offshore, through the process of "longshore drift." The natural movement of sand on and offshore as well as alongshore (up and down the coast or longshore drift) is essential to maintaining a sustainable coastal ecosystem.[130]

[129] Davidson-Arnott, R., Bauer, B., and Houser, C. (2019). *Introduction to Coastal Processes and Geomorphology, Second Edition.* Cambridge University Press.
[130] Ibid.

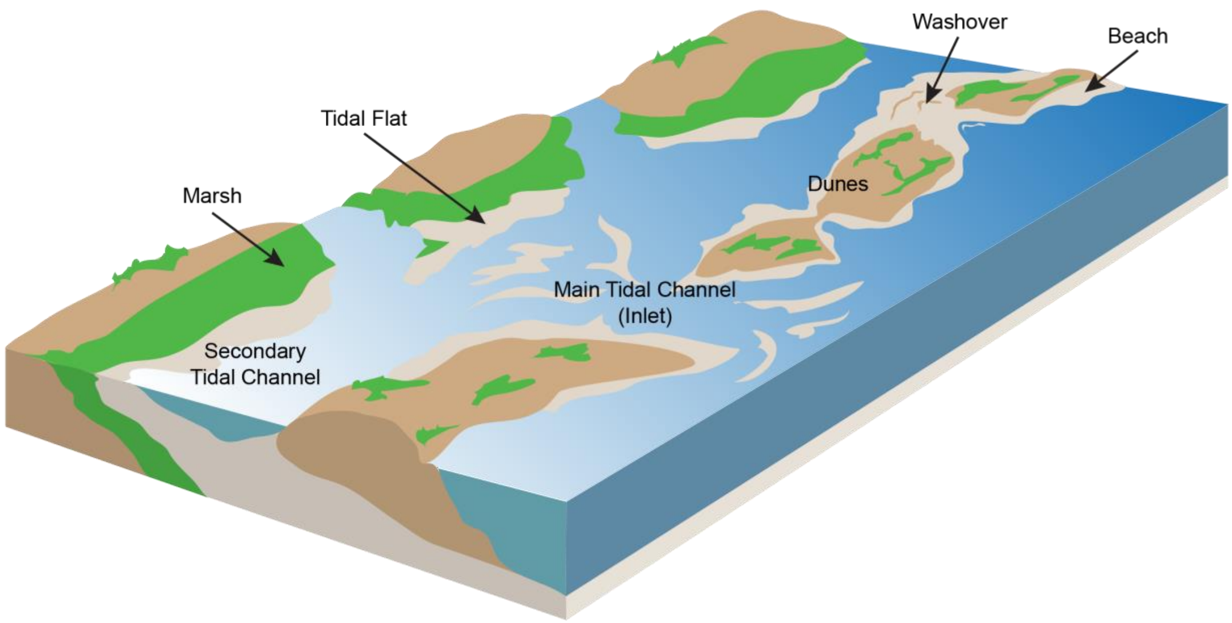

Figure 1.30 Coastal sandy system with its beach, dune, and barrier components (after Davidson-Arnott[131])

Climate change impacts, through sea level rise, could lead to further landward retreat of beach and dune systems, if this retreat is not blocked by natural features (e.g., cliffs) or human-built structures (coastal squeeze). Larger and more frequent storms could lead to increased erosion of the seaward-facing front of dunes (scarp) as well as decreasing the recovery time between storms, with increased damage occurring when dunes have not had a chance to fully recover between storms. Larger waves and storm surge, in conjunction with sea level rise, could also lead to increased "washovers" that occur when waves overtop or break through (breach) small dunes.[132] Climate change impacts in coastal sandy systems can be managed through beach nourishment as well as dune building and restoration. Dunes act as a natural barrier protecting the environments and infrastructure behind them, so their maintenance and protection is important in a changing climate.

[131] Ibid.
[132] Ibid.

Table 5.2 Factors and concerns for management options for sandy coastal systems[133,134,135,136]

Driving Factors	• Tides and waves supply and transport sediment along all components of the system. They are crucial in the formation of barrier systems as waves carry and deposit sediment in offshore bars during the fall/winter and return sediment to the beach during the spring/summer. • Grain size helps control the beach slope and rate of recovery after a storm. The size is dependent on geology and local glacial history. • Sediment supply promotes growth and recovery of sandy systems from storm events requires a natural source of sediment. This may be from a marine or river source. • Wind blows sediment inland and is crucial for dune development. • Vegetation traps and protects windblown sand, helping to build and stabilize dunes.
Impact Concerns	• Sea level rise expands the ocean's reach and causes numerous concerns for erosion, flooding, and storm surge. • Sea level rise will result in increased erosion in the coastal zone not previously exposed to water. The extent of reach depends on the tidal range. • The system is highly susceptible to flood conditions. Over-wash in dune and barrier systems can flatten coastal features as the sediment moves landward or is carried away through ocean currents. • Unsuitable protection structures or blocked longshore drift can lead to erosion and loss of the system. Coastal squeeze occurs when built structures block sediment movement and therefore the ability of coastal sandy systems to naturally grow in elevation with sea level, leading to their eventual loss. • Dunes are especially vulnerable to human impact. ATVs driving and people walking over them can lead to long-term damage. Damage to vegetation can lead to destabilization. Even depressions left by footprints can expose them to wind damage (blowouts).
Management Options	• The most sustainable and natural form of protection is to allow the beach to maintain its dynamic nature by permitting sand to move back and forth through the system, seasonally and during storms. This mobility is particularly important for dune development, which requires the unblocked transfer of sand to sustain the dune. • Beach nourishment can add sediment into the system. When dredging has to take place for boat access to a channel or port, consideration could be given to using the removed sediment for beach nourishment as long as the sediment has the same consistency (mix of grain sizes) as the beach. • Care should be taken in the construction of protective structures in the nearshore zone where they are necessary, whether perpendicular (e.g., seawall) or parallel (e.g., groynes) to the coast.

[133] Bird, E. (2001). *Coastal Geomorphology: An Introduction.* New York: John Wiley & Sons Inc.
[134] Davidson-Arnott, R., Bauer, B., and Houser, C. (2019). *Introduction to Coastal Processes and Geomorphology, Second Edition.* Cambridge University Press.
[135] Linham, M. M., & Nicholls, R. J. (2010). *Technologies for Climate Change Adaptation: Coastal Erosion and Flooding.* UNEP Risø Centre on Energy, Climate and Sustainable Development, 166 pp.
[136] Hobbs, C.H. (2012). *The Beach Book: Science of the Shore.* New York: Columbia University Press.

	• Minimize human impact on dunes through the construction of boardwalks or mesh-covered paths for beach access and (mesh/permeable) fencing around the base of dunes (Figure 1.29) to restrict access, protect embryo dunes, and allow natural regrowth or regeneration of damaged areas while maintaining sediment exchange between the beach and dunes. • Retreat through relocation of human activities and/or infrastructure out of the coastal zone, leaving room for dunes to naturally move landward.

5.3 Intertidal flat (sand or mud)

The intertidal zone is located between the high and low tide lines (Figure 1.33) and is flooded periodically depending upon tidal conditions. These conditions assist in the creation and development of intertidal flats, which are the accumulation of fine-grained or mud (silt or clay) or sandy sediments along a gentle slope. Intertidal flats are formed in areas where there is a significant supply of fine-grained sediment and tidal influence is the greatest fluid force. Tidal currents and wave energy are essential in transporting sediments inshore.

Typically, both sand and mud are present on flats, with the sandy materials accumulating in the lower portion and the muddy, organic carbon rich material building the top half.[137] Any vegetation located on intertidal flats is salt tolerant and able to survive during high tide or ocean flooding as well as when it is exposed during low tide. Vegetation that grows on intertidal flats could include seagrasses such as eelgrass (*Zostera marina* Linnaeus)[138,139] and various species of seaweeds commonly known as rockweeds (e.g., *Ascophyllum spp., Fucus spp., F. vesiculosus*), including bladderwrack and knotwrack.[140] Eelgrass has been designated as an Ecologically Significant Species (ESS) by the Department of Fisheries and Oceans (DFO); it reaches only into the lowest portion of the intertidal zone from the nearshore zone since it is a plant that thrives underwater.[141] Rockweeds are located in the lower to mid-portion of the intertidal zone, and the upper-limit of their range is controlled by their ability to resist heat and drying out when they are uncovered at low tide. It is important to note that they require something solid to attach themselves to, so they appear on intertidal flats only when there are large rocks to act as anchors.[142]

Figure 1.31 Intertidal flat in Grand Pre, NS, 2015 (Graeme Matheson, Saint Mary's University)

[137] Gao, S. (2009). Geomorphology and Sedimentology of Tidal Flats. In G.M.E. Perillo, E. Wolanski, D.R. Cahoon, M.M. Brinson (Eds.), *Coastal Wetlands: An Integrated Ecosystem Approach* (Ch. 10, pp. 295-312). Amsterdam: Elsevier.
[138] DFO. (2009). *Does eelgrass (Zostera marina) meet the criteria as an ecologically significant species?* DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/018.
[139] Murphy, G.E.P, Dunic, J.C., Adamczyk, E.M., Bittick, S.J., Côté, I.M., Cristiani, J., Geissinger, E.A., Gregory, R.S., Lotze, H.K., O'Connor, M.I., Araújo, C.A.S., Rubidge, E.M., Templeman, N.D., and Wong, M.C. (2021). From coast to coast to coast: ecology and management of seagrass ecosystems across Canada. FACETS. 6: 139-179. https://doi.org/10.1139/facets-2020-0020
[140] Maine Department of Marine Resources & Rockweed Plan Development Team. (2014). Fishery Management Plan for Rockweed (Ascophyllum nodosum). 55 pp. Retrieved from: https://repository.library.noaa.gov/view/noaa/38001
[141] Murphy, G.E.P, Dunic, J.C., Adamczyk, E.M., Bittick, S.J., Côté, I.M., Cristiani, J., Geissinger, E.A., Gregory, R.S., Lotze, H.K., O'Connor, M.I., Araújo, C.A.S., Rubidge, E.M., Templeman, N.D., and Wong, M.C. (2021). From coast to coast to coast: ecology and management of seagrass ecosystems across Canada. FACETS. 6: 139-179. https://doi.org/10.1139/facets-2020-0020
[142] Maine Department of Marine Resources & Rockweed Plan Development Team. (2014). Fishery Management Plan for Rockweed (Ascophyllum nodosum). 55 pp. Retrieved from: https://repository.library.noaa.gov/view/noaa/38001

Figure 1.32 Intertidal flats in NB (1.32a, left: Point Wolfe beach, Fundy National Park; 1.32b, right: West Quaco; Jenna Miller)

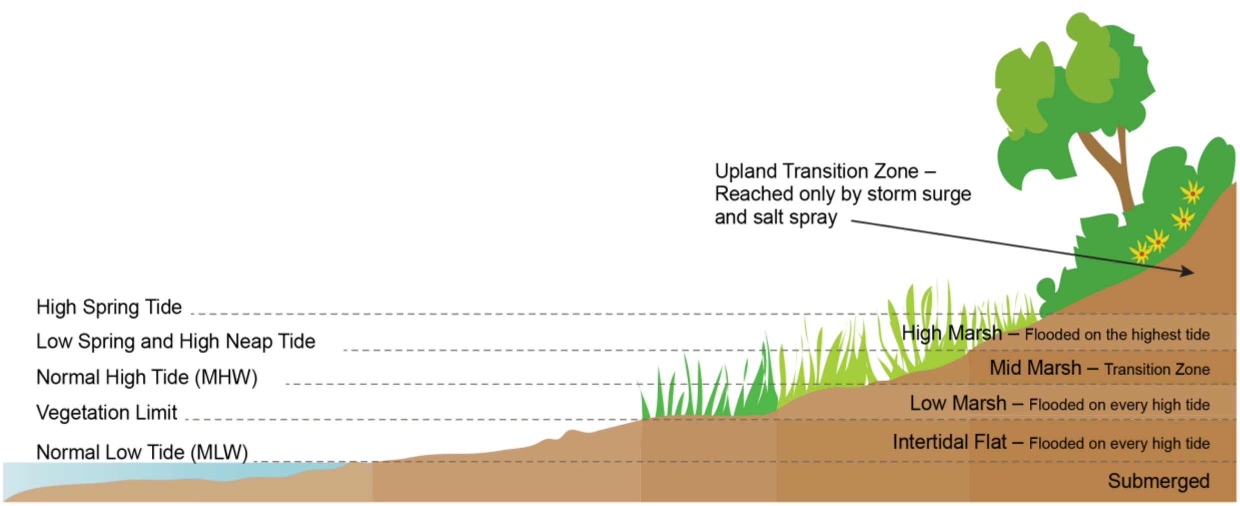

Figure 1.33 Transition zones from intertidal flats to low and high salt marshes

Table 6.3 Factors and concerns for management options for intertidal flats[143,144,145,146,147]

Driving Factors	• Tides and waves supply and transport sediment to small bed slopes along the coast. • Larger tidal ranges allow more area for tidal flat development. • Flats occur in areas with a gentle slope (nearshore slope). • Sediment supply comes from rivers which deposit sediment into estuaries or are eroded from adjacent coastal areas. • Vegetation traps sediment to allow for further flat development. It can decrease erosion caused by waves and currents.
Impact Concerns	• Sea level rise expands the ocean's reach and causes numerous concerns for erosion, flooding, and storm surge. • Depending on tidal conditions, sea level rise will result in increased erosion within areas of the coastal zone that initially were not exposed to water. • Low-lying areas are highly susceptible to flood conditions. Storm surges can drastically affect flats, where wave action can erode, transport, or accumulate sediment in different areas. Some areas might experience increased flat erosion while others could receive increased sediment deposition. • Unsuitable protective structures or blocked longshore drift can lead to erosion and loss of the system.
Management Options	• Similar to coastal sandy systems, intertidal flat areas are dynamic places. • While intertidal flats are not usually developed, they can still be subject to damaging human influence. They can accumulate pollutants in their sediments from on-land sources, and vehicles driving over intertidal flats can be very damaging to invertebrate species that are critical food sources for migratory birds (in particular on the extensive flats of the Upper Bay of Fundy). • The most sustainable and natural way to protect the coastline is to allow the flat to maintain its natural responsiveness by allowing sediment to move back and forth through the system seasonally and during storm events.

[143] Gao, S. (2009). Geomorphology and Sedimentology of Tidal Flats. In G.M.E. Perillo, E. Wolanski, D.R. Cahoon, M.M. Brinson (Eds.), Coastal Wetlands: An Integrated Ecosystem Approach (Ch. 10, pp. 295-312). Amsterdam: Elsevier.
[144] Bird, E. (2001). *Coastal Geomorphology: An Introduction.* New York: John Wiley & Sons Inc.
[145] Davidson-Arnott, R., Bauer, B., and Houser, C. (2019). *Introduction to Coastal Processes and Geomorphology, Second Edition.* Cambridge University Press.
[146] Linham, M. M., & Nicholls, R. J. (2010). *Technologies for Climate Change Adaptation: Coastal Erosion and Flooding.* UNEP Risø Centre on Energy, Climate and Sustainable Development, 166 pp.
[147] Hobbs, C.H. (2012). *The Beach Book: Science of the Shore.* New York: Columbia University Press.

5.4 Salt marshes

Salt marshes are vegetated areas located within the upper portion of the intertidal zone; they are exposed during low tide, submerged during high tide, and bordered on the seaward edge by intertidal flats. Plants located in salt marshes are salt tolerant and able to survive during high tide or ocean flooding[148] (Figure 1.34).

Salt marshes are highly adaptive and grow quickly when given new opportunities. They form in calm, sheltered areas with low wave energy, such as in estuaries, bays, and lagoons. They have been proven to diminish wave action and height in some areas by more than 50%.[149,150] However, these systems depend on a balance between sediment build-up through a) inorganic material that accumulates with every tide, during storms, or from ice blocks on the marsh surface, and b) below ground production from the growth of the plant root system. All factors serve to increase the elevation of the marsh base with rising sea levels (Figure 1.35).

Figure 1.34 Cheverie Creek Marsh, NS, during high tide, 2014, nine years after restoration (Christa Skinner)

Salt marshes can generally be divided into two zones, the low marsh and the high marsh, based on the frequency and length of tidal submergence and dominant plant species. The low marsh extends from the lower transitional boundary with the intertidal (mud)flats up to the mean high tide line; this means that it experiences flooding during every high tide. The high marsh extends above the mean high tide line to the height of spring high tides, so it is only flooded for a short time during the highest tides of the month. Due to the stress that flooding and salt put on vegetation, the low marsh zone is dominated by only one or two species and the number of species increases through the high marsh. Salt marshes may also be referred to as tidal wetlands or tidal marshes, a class which includes more brackish (less salt) and some freshwater species higher in the intertidal zone, typically located at the upper reaches of tidal rivers.

[148] Bird, E. (2001). *Coastal Geomorphology: An Introduction.* New York: John Wiley & Sons Inc.
[149] Ibid.
[150] Davidson-Arnott, R., Bauer, B., and Houser, C. (2019). *Introduction to Coastal Processes and Geomorphology, Second Edition.* Cambridge University Press.

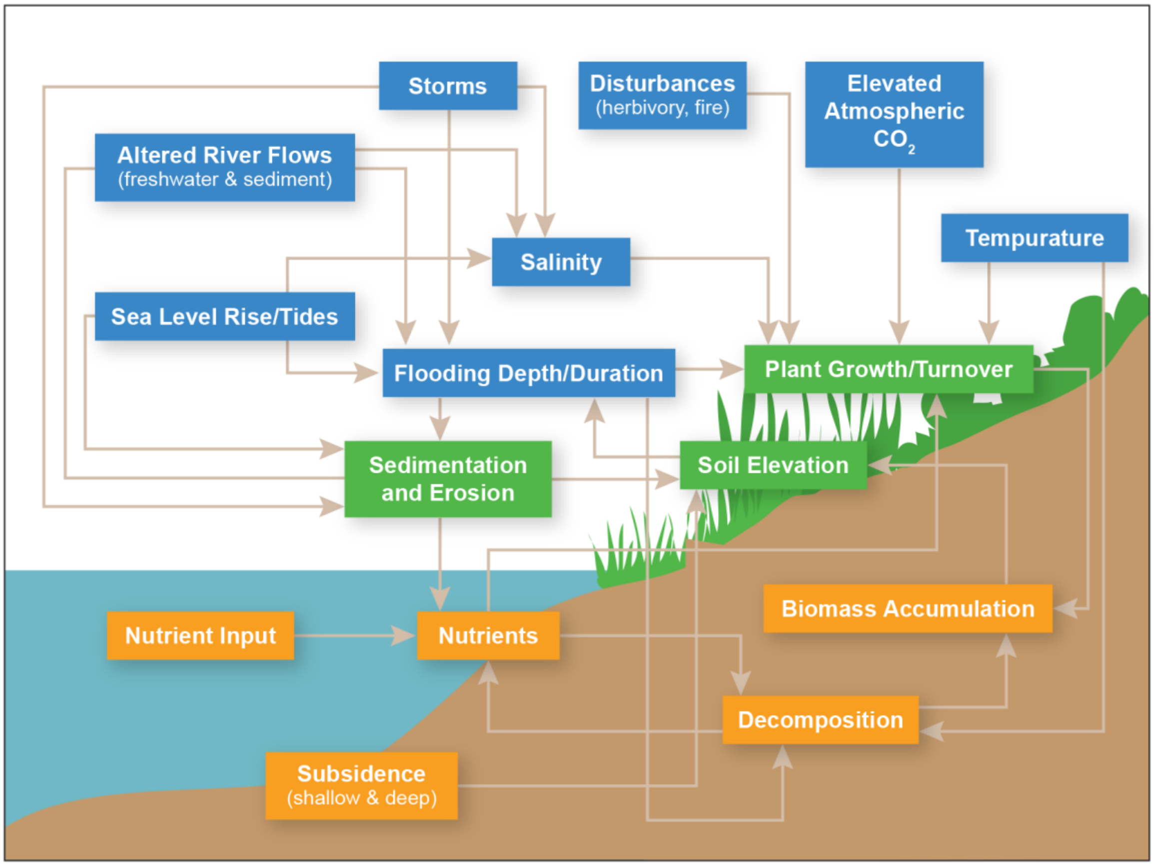

Figure 1.35 Salt marsh drivers and processes contributing to changes in surface elevation and survival to sea level rise (after Roman)[151]

Climate change will impact salt marshes though sea level rise. The ability of a salt marsh to survive rising sea levels is dependent on the rate at which sediment accumulates in the marsh. If sedimentation rates do not allow a salt marsh to accrete rapidly enough to outpace sea level rise, then the marsh could slowly drown. Where sedimentation rates are high, for instance in the upper Bay of Fundy, salt marshes should be able to outpace sea level rise if they have the space necessary to grow in height as they move landward; however, if their landward retreat is blocked by hard built structures such as a dykes, they could experience coastal squeeze.[152] The impact of coastal squeeze could be reduced through managed realignment of dykes and other hard infrastructure blocking the retreat and inland growth of salt marshes. In fact, allowing the growth of salt marshes and restoring former marshes is a form of adaptation to climate change. As the marshes reduce wave energy, they can decrease erosion and protect the infrastructure inland.[153,154]

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[151] Roman, C.T. (2017). Salt Marsh Sustainability: Challenges During an Uncertain Future. *Estuaries and Coasts, 40*: 711-716.
[152] Ibid.
[153] Ibid.
[154] van Proosdij, D., Manuel, P., Sherren, K., Rapaport, E, McFadden, C., Rahman, T., and Reeves, Y. (2021). *Making Room for Movement: A framework for implementing nature-based coastal adaptation strategies in Nova Scotia.* TransCoastal Adaptations Centre for Nature-based Solutions, Saint Mary's University. Prepared for Natural Resources Canada.

Table 5.4 Factors and concerns for management options for salt marshes[155,156,157]

Driving Factors	• Tides and waves carry and deposit sediment in addition to those deposited by fluvial (river) processes. • Changes in the surface, based on the rate of sediment deposition and contributions of below ground production within the root zone, can change the elevation withing tidal range. Elevation increases as sediment accretes on the marsh surface or plant root systems expand. • Ample sediment supply leads to opportunity for marsh growth and smaller grain sizes require calmer conditions in order to be deposited (silts and clays generally make up the sediment in salt marshes). Salt marshes on the Atlantic and Gulf coasts may contain more sandy material. • Vegetation traps sediment to enhance accretion and slow down wave energy. Below ground production by plant roots helps the salt marsh to grow in height. • Topography of the coastline behind a marsh (e.g., a cliff) could be a natural barrier blocking a salt marsh from retreating landward (coastal squeeze).
Impact Concerns	• Sea level rise impact is dependent on the rate of sediment deposition. If the rate of sediment deposition cannot keep up with sea level, salt marsh habitat can drown. • Erosion is caused by exposed wave energy, low sediment supply, and bioturbation (disturbance of sediments by, e.g., crabs). Sediment resuspended from tidal flats is an important source for the marsh system, and thus a lack of sediment can reduce the marsh. • Hard engineered structures or natural features such as a cliff or steep slope could restrict the inland movement of salt marshes in response to rising sea levels (coastal squeeze).
Management Options	• Marshes are naturally highly adaptable to changing sea levels and shoreline position: they dissipate wave energy while acting as a natural flood detention area, and also provide habitat for invertebrates, birds, and fish. • Implementing plans to allow for salt marsh growth or stability can act as a flooding management strategy. • A combination of hard (rocks) and soft (plants) intervention options can help in re-establishing a salt marsh. • Strategic planning can encourage the development of watershed management and wetland policies. • Managed realignment of dykes (and other hard engineered structures) allows increased accommodation space for the landward shift of marshes with sea level rise (SLR) and salt marsh regrowth to prevent coastal squeeze. Removal of tidal barriers (e.g., culverts, aboiteau) may also permit the expansion of salt marsh upstream.

[155] Bird, E. (2001). *Coastal Geomorphology: An Introduction.* New York: John Wiley & Sons Inc.
[156] Davidson-Arnott, R., Bauer, B., and Houser, C. (2019). *Introduction to Coastal Processes and Geomorphology, Second Edition.* Cambridge University Press.
[157] Linham, M. M., & Nicholls, R. J. (2010). *Technologies for Climate Change Adaptation: Coastal Erosion and Flooding.* UNEP Risø Centre on Energy, Climate and Sustainable Development, 166 pp.

5.5 Cobble beaches

Cobbles are small rocks that range in size from a tennis ball to a volleyball.[158] Cobble beaches are made up of glacial till and other rock materials from sediment that accumulated along the coast when the glaciers retreated after the last ice age. Cobble beaches are generally much steeper in comparison to sandy beaches.[159,160] They are typically formed in island and headland areas where they are fed by erosion to drumlins (long, elongated hills made up of sediment left behind by the retreat of glaciers) along the coast[161] (Figure 1.36).

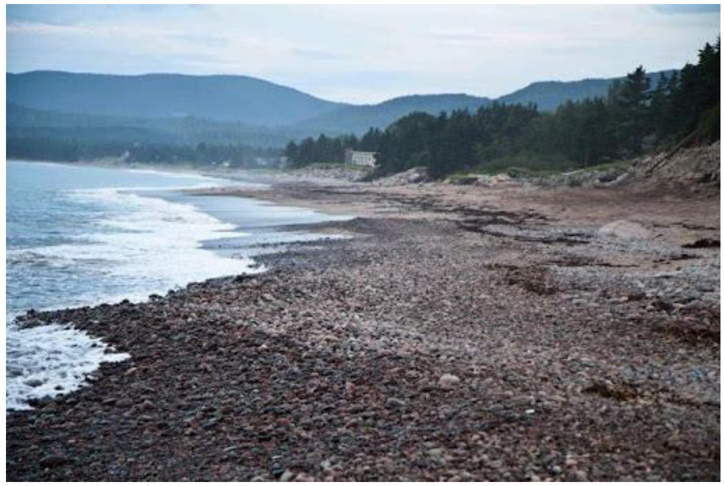

Figure 1.36 Example of cobble beach Ingonish, NS (Don Jardine)

Cobble beach shores do not erode easily, but they are susceptible to movement during large storms, and are increasingly threatened as sea level rise increases storm-surge heights (Figure 1.37). Most of the movement is in a landward direction, making cobble beaches and barriers susceptible to coastal squeeze if they do not have the space to naturally retreat landward.

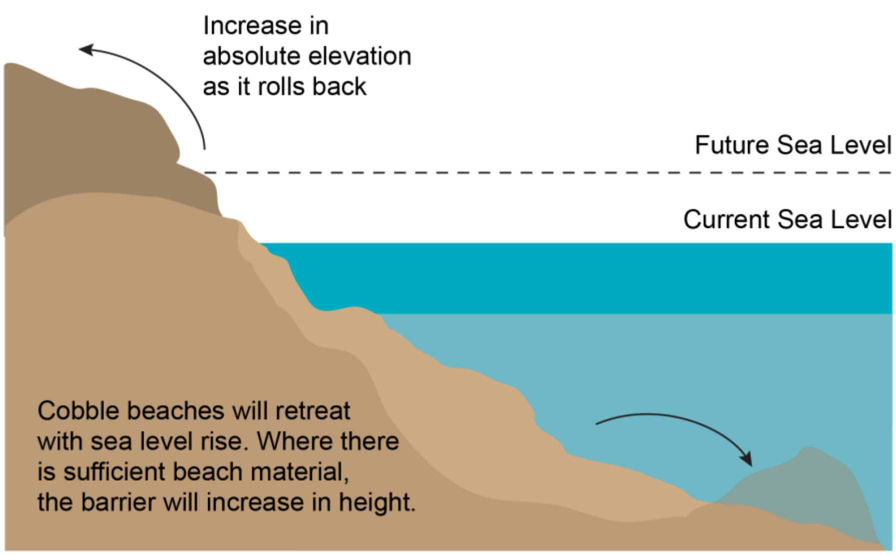

Figure 1.37 Cobble beach coastal processes (modified from Wratt et al.[1])

[158] Butler, M., Chiasson, R.D., Daury, R.W., Dean, S., Dietz, S.B., MacKinnon, N., and Steel, J. (1996). Module 9: Cobble Beaches in *By the Sea: A Guide to the Coastal Zone of Atlantic Canada*, Department of Fisheries and Oceans, 40 pp.
[159] Ibid.
[160] Davidson-Arnott, R., Bauer, B., and Houser, C. (2019). *Introduction to Coastal Processes and Geomorphology, Second Edition.* Cambridge University Press.
[161] Butler, M., Chiasson, R.D., Daury, R.W., Dean, S., Dietz, S.B., MacKinnon, N., and Steel, J. (1996). Module 9: Cobble Beaches in *By the Sea: A Guide to the Coastal Zone of Atlantic Canada*, Department of Fisheries and Oceans, 40 pp.

Table 5.5 Factors and concerns for management options for cobble beaches[162,163,164,165]

Driving Factors	• Cobbles derived from glacial till and other rock materials were deposited along the coast during glacial retreat. The erosion of drumlins and hills formed by glacier retreat, provided cobble sediment for beaches within a limited distance. • High wave energy launches cobbles further up shore in the development of the beach. Development of the beach is limited to the strength of wave energy and its ability to move cobble.
Impact Concerns	• Sea level rise will flood and submerge cobble sediment. Wave energy in normal conditions may not be strong enough to move cobble inland. • Storm surge increases intensity, allowing cobble to be launched easily, potentially causing damage to critical infrastructure such as roads near the shore. A storm surge could breach a cobble beach, forming an inlet and impacting the area behind it. • Topography or built structures directly behind the cobble beach (e.g., cliff) could block its natural landward retreat in response to rising sea levels (coastal squeeze).
Management Options	• There is limited research on management options for cobble beach systems. • Cobble beaches are relatively resistant to erosion, although less resistant than rocky shores. • As flooding is more of an issue for infrastructure adjacent to cobble beaches, flooding management options would be appropriate, such as raising buildings and flood proofing. • Land use planning of setbacks and restrictions will minimize the threat. • Managed retreat should be considered when it is possible.

[162] Bird, E. (2001). *Coastal Geomorphology: An Introduction.* New York: John Wiley & Sons Inc.
[163] Davidson-Arnott, R., Bauer, B., and Houser, C. (2019). *Introduction to Coastal Processes and Geomorphology, Second Edition.* Cambridge University Press.
[164] Butler, M., Chiasson, R.D., Daury, R.W., Dean, S., Dietz, S.B., MacKinnon, N., and Steel, J. (1996). Module 9: Cobble Beaches in *By the Sea: A Guide to the Coastal Zone of Atlantic Canada*, Department of Fisheries and Oceans, 40 pp.
[165] Linham, M. M., & Nicholls, R. J. (2010). *Technologies for Climate Change Adaptation: Coastal Erosion and Flooding.* UNEP Risø Centre on Energy, Climate and Sustainable Development, 166 pp.

4.1 Cliffs, bluffs, and banks (cohesive shores)

Cliffs, bluffs, and banks are naturally eroding features that provide sediment for nearby coastal environments where sediment builds up (sandy/cobble beaches, estuaries, intertidal flats, and salt marshes). They are composed of a mixture of hard and soft rock material or cohesive materials such as silt and clay. Cliffs and bluffs typically have steep slopes greater than 40°.[166,167] Cliffs generally exceed heights of eight metres while bluffs can range between three to eight metres, and banks do not exceed more than three metres (Figure 1.38).[168]

Figure 1.38 Bank in Cavendish, PEI, 2013 (Samantha Page)

Figure 1.39 Eroding Cliff/Bluff, PEI (Jenna Miller)

The type of rock or cohesive material influences how resistant the cliff, bluff, or bank is to wave action. A bluff comprising material such as glacial till can experience rapid erosion.[169,170] Glacial till is an unsorted mixture of sediment that was deposited by glaciers as they retreated during the last ice age. In some places, till forms specific glacial features like the drumlins that are present on the Atlantic coast of Nova Scotia; these are eroding due to the soft nature of the till.[171] While all cohesive shores are experiencing erosion, there is an exceptional amount of erosion occurring in Prince Edward Island in comparison to the other Atlantic provinces (Figure 1.39).

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[166] Bird, E. (2001). *Coastal Geomorphology: An Introduction.* New York: John Wiley & Sons Inc.
[167] Charlton, R. (2008). *Fundamentals of Fluvial Geomorphology.* New York, NY: Routledge.
[168] Davies, M. (2011). *Geomorphic Shoreline Classification of Prince Edward Island.* Report prepared by Coldwater Consulting Ltd for the Atlantic Climate Adaptation Solutions Associations (ACASA), 66 pp.
[169] Bird, E. (2001). *Coastal Geomorphology: An Introduction.* New York: John Wiley & Sons Inc.
[170] Davidson-Arnott, R., Bauer, B., and Houser, C. (2019). *Introduction to Coastal Processes and Geomorphology, Second Edition.* Cambridge University Press.
[171] Forde, T.C., Nedimović, M.R., Gibling, M.R., and Forbes, D.L. (2016). Coastal Evolution Over the Past 3000 Years at Conrads Beach, Nova Scotia: the Influence of Local Sediment Supply on a Paraglacial Transgressive System. *Estuaries and Coasts* 39, 363–384. https://doi.org/10.1007/s12237-015-0016-6

Table 5.6 Factors and concerns for management options for cliffs, bluffs, and banks[172,173,174,175]

Driving Factors	• Consistent wave action wears down rock or fine material. • Exposure to rain, temperature changes, and evaporation of moisture contribute to the wearing down of rock or fine material. • Large rainfall events lead to increased runoff (overland flow) over short periods of time, increasing weathering processes. • The type of rock material (how hard or soft it is) determines the resistance to erosion, and the layering of material matters.
Impact Concerns	• The rate of erosion is dependent upon the resistance of material. Erosion can be experienced at the toe from wave action or at the crest from slumping and slow drainage. • Inundation (flooding) or submergence (covered with water) can occur as a result of sea level rise. Infrastructure along the backshore will experience flooding if lower banks or bluffs are present. The location of erosion will move upward along the profile. • Higher wave energy from storm surges will cause infrastructure damage and greater erosional capacity. • Under a changing climate, larger and more intense precipitation events could lead to more rain falling at once, leading to increased runoff (overland flow), gullying, and subsequent slumping. • Cliff face failure can occur when material along the face is removed as the result of various erosion processes such as: undercutting, mass wasting, freeze-thaw processes, overland flow, piping, drilling, or gullying.
Management Options	• Retreat is the best option where possible. • Land use restrictions and setbacks may be necessary for cliff, bluff, or bank environments, factoring in the rate of recession and stability. • Cliff, bluff, or bank stabilization can be implemented along the toe (bottom) or the crest (top) through planting vegetation or rock armouring. Bank stabilization can also be implemented by re-grading the slope. • Stabilization is only possible outside the habitat of endangered bank swallows. • Creation of a drainage management plan is necessary.

[172] Charlton, R. (2008). *Fundamentals of Fluvial Geomorphology.* New York, NY: Routledge.
[173] Bird, E. (2001). *Coastal Geomorphology: An Introduction.* New York: John Wiley & Sons Inc.
[174] Davidson-Arnott, R., Bauer, B., and Houser, C. (2019). *Introduction to Coastal Processes and Geomorphology, Second Edition.* Cambridge University Press.
[175] Linham, M. M., & Nicholls, R. J. (2010). *Technologies for Climate Change Adaptation: Coastal Erosion and Flooding.* UNEP Risø Centre on Energy, Climate and Sustainable Development, 166 pp.

5.7 Rocky shores

Compared to the other types of coastal systems, rocky shores are one of the most resistant to the impacts of weathering and erosion. Erosion happens relatively slowly, however, generally not at the same rate along a coastline due to differences in rock type (i.e., material strength), layers, and fractures (Figure 1.40; Figure 1.41). In terms of sea level rise, although the erosion rate does not accelerate, the elevation at which erosion takes place does change.[176]

Development near rocky shores will be highly and increasingly vulnerable to flooding and storm surge events due to climate change. This vulnerability results from the combination of their low-lying nature and inadequate drainage that results from runoff during storms. In addition, increased water depth at the base of the cliff can increase the height of waves (and therefore energy) breaking against the toe, accelerating erosion from wave and water action.

Figure 1.40 Rocky shore of erodible sandstone, PEI (Samantha Page)

Figure 1.41 Resistant rocky shores, 1.41a, Cape Spear; 1.41b, Pouch Cove,NL (Sepehr Khosravi)

[176] Davidson-Arnott, R., Bauer, B., and Houser, C. (2019). *Introduction to Coastal Processes and Geomorphology, Second Edition.* Cambridge University Press.

Table 5.8 Factors and concerns for management of rock shores[177,178]

Driving Factors	• Consistent wave action wears down rock material. The type of rock material determines the resistance to erosion and weathering. • Exposure to rain, temperature changes and evaporation of moisture contribute to the wearing down of rock material.
Impact Concerns	• Sea level rise causes inundation (flooding) or submergence (covered with water) can occur. Solid rock will not "build up" when flooded, it will be submerged under water. Any infrastructure along the backshore will experience flooding. The location of erosion will move upward along the profile. The rate of erosion will not change if it is hard rock. • Rising sea levels will allow for storm surges to travel further inland, threatening nearby infrastructure. Deeper water will allow larger waves to reach the rocky cliff resulting in increased rates of erosion at the toe and potential for rock falls.
Management Options	• Limited research has been conducted regarding management opportunities for rocky shores. • There are not many engineering tools applicable for rocky shores, due to the resistance of these coastlines. • Land use planning tools, such as regulations, restrictions, and land use changes would be appropriate to provide relief from impacts of flooding. • Managed retreat is the best option where possible.

[177] Bird, E. (2001). *Coastal Geomorphology: An Introduction.* New York: John Wiley & Sons Inc.
[178] Davidson-Arnott, R., Bauer, B., and Houser, C. (2019). *Introduction to Coastal Processes and Geomorphology, Second Edition.* Cambridge University Press.

5.8 Developed and managed coasts

There are four groups of developed and managed coasts:

- highly built settlements (towns)
- low density settlements (private property along the coast such as a row of cottages)
- agricultural land (includes both livestock grazing and crop fields) and
- managed areas, which are non-residential, important human assets (e.g., sewage and water treatment plants, wharves, roads, and bridges).

5.8.1 Highly built settlements

A highly built settlement refers to a concentration of residential and supporting development (such as a town) (Figure 1.42). Highly built settlement areas typically have centralized services like domestic water, sewer, waste management, and fire and security services. There is usually support for maintaining community infrastructure. Highly built settlements tend to evolve as a cluster of economic activity,[179] with a higher community income that is associated with both primary industries (natural resources) and commercial services.

Figure 1.42 Trinity, NL (Sepehr Khosravi)

The capacity to adapt to rising sea levels varies among highly built settlements, but local governments and property owners may have access to resources that aid in land use planning or engineering adaptation approaches. For example, people living in towns may have greater access to resources through government funding and institutional partnerships located in the area. The expertise and workforce that come from such partnerships can provide easier access to successful adaptation strategies.

Residents within towns therefore benefit from these supports: adaptation can benefit everyone in the community collectively, and also individually, especially those with shoreline property. However, there will often be differing understandings and views about adaptation and the best strategies to pursue. The process of deciding on adaptation needs to involve as wide a range of community members and stakeholders as possible to ensure the most widely acceptable approach that provides the greatest possible benefit. To that effect, when deciding on

[179] Freshwater, D. (2004). Delusions of grandeur: The search for a vibrant rural America. In G. Halseth and R. Halseth (Eds.), *Building for Success: Exploration of Rural Community and Rural Development* (Ch 2., pp. 2, 9 50). Calgary, AB: Rural Development Institute.

adaptation strategies to implement, coastal property owners should make an effort to discuss and plan along with their neighbours. This is especially important when adapting involves the construction of engineered structures that could alter sediment transport, erosion and accretion patterns because structures built on a property could impact those that neighbour it. For example, if a property owner constructs a riprap revetment the length of their shoreline, their neighbours could end up facing higher rates of erosion than before since there is often increased erosion around the ends of riprap revetments; or should a property owner build a groyne or other shore-perpendicular structure to encourage the buildup of the beach on their property, their downdrift neighbour could face increased erosion as the groyne blocks sand from being transported onto their property. Additionally, planning with neighbours can allow property owners to share the cost of implementing the adaptation options that are selected. Discussions could be facilitated through homeowner associations or other collective groups.

5.8.2 Low density settlements

Low density settlements are rural residential areas outside of highly built settlements (Figure 1.43). Central infrastructure (like water and sewer) does not exist in low density settlements; property owners manage their own water supply and sewage disposal. Access to services can be limited by long distances between where people live and where services are located, including community services such as fire, police, and health care services.[180] These long distances can be isolating, and during emergencies that involve flooding, for example, people can be cut off from help, including emergency services, and distant neighbours.

Figure 1.43 Western Bay Area, NL (Sepehr Khosravi)

Property owners in low density settlements may need to bear the cost and effort of adaptation individually, and the costs can be high if a property owner's coastal vulnerability is severe. The degree of coastal hazard will determine the feasibility—environmental and economic—of remaining in an area.

[180] Ibid.

5.8.3 Agriculture

Agricultural areas are lands dedicated to the production of food—grains, fruits, vegetables, and livestock. Encroaching flooding and erosion associated with rising sea levels makes agriculture in coastal areas vulnerable, affecting not only a farmer's crop yield, but the availability of land to support agricultural activities.[181] In Atlantic Canada for example, dykes, protect coastal agricultural land from flooding, mostly along the Bay of Fundy shore, and this agricultural land is considered to be the most arable land in Nova Scotia (Figure 1.44). However, these dykes, no longer only protect agricultural land (but even entire towns in some cases), and with the threat of rising sea levels, they must be elevated or realigned to ensure continued protection against the increasing risk of flooding.

Figure 1.44 Agricultural land protected by dykes, Sackville, NB (Sabine Dietz)

The importance of protecting these areas extends beyond the economic and personal well-being of the farmer; food supply is a societal concern.

[181] Dasgupta, P., Morton, J.F., Dodman, D., Karapinar, B., Meza, F., Rivera-Ferre, M.G., Toure Sarr, A., and Vincent, K.E. (2014). Rural areas. In Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK and New York, NY: Cambridge University Press, pp. 613-657.

5.8.4 Managed areas

Managed areas are locations that are monitored and maintained due to their importance for general support to community activity and development. Managed areas can include recreational areas such as parks, historical landmarks, and assets necessary for the proper operation of a community. Infrastructure is considered to be any feature that supports societal needs such as transportation (e.g., roads, bridges, and wharfs) (Figure 1.45), water supply, and waste management, among others. Exposure to flooding, sedimentation, and erosion can cause temporary or permanent damage to or loss of these structures.[182] Losing critical infrastructure can significantly affect a community's (or an individual's) access to emergency aid, clean water, and waste disposal. There is a legacy of road and rail infrastructure built in low-lying coastal areas in the region, such as the Canso Causeway. Wastewater treatment facilities are often located near sea level to take advantage of gravity drainage (avoiding or reducing the need to pump wastewater to the facility for treatment), leaving these critical infrastructures vulnerable to coastal impacts. Infrastructure requires regular maintenance to avoid damage and deterioration.

Figure 1.45 St. Martins wharf and covered bridge, NB (Jenna Miller)

5.8.5 Special case: dykelands

Dykelands are former low-lying salt marshes that have been reclaimed from the sea and isolated from tidal flooding through the construction of dykes (Figure 1.46) and aboiteaux (Figure 1.47). They are of strategic importance for climate change adaptation in the Bay of Fundy region. At the present time, in Nova Scotia and New Brunswick, there are 322 km of dykes protecting more than 31,860 ha of agricultural land.[183,184] Dykes are the second line of defense after coastal wetlands and are no longer simply protecting agricultural land. Residential and commercial development has taken place on adjacent lowlands, which are now vulnerable to flooding from dyke overtopping or breaching. This development includes private homes, municipal sewage lagoons, public roads, and rail and utilities, including the Trans-Canada Highway and CN Rail between Nova Scotia and New Brunswick. The Landscape of Grand Pré in Nova Scotia, a dykeland area, has also been internationally protected as an UNESCO World Heritage Site for its cultural importance.[185] Because of the complex land use, dykes and the dyke-protected lowland present a specific adaptation challenge. Different agencies are responsible for their maintenance (Part 2, Chapter 2).

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[182] Ibid.
[183] Government of New Brunswick Department of Transportation and Infrastructure. (n.d.) *Marshland Maintenance.* Retrieved May 17, 2022 from https://www2.gnb.ca/content/gnb/en/services/services_renderer.201405.Marshland_Maintenance_.html#serviceDescription
[184] Sherren, K., Ellis, K., Guimond, J.A., Kurylyk, B., LeRoux, N., Lundholm, J., Mallory, M.L., van Proosdij, D., Walker, A.K., Bowron, T.M., Brazner, J., Kellman, L., Turner II, B.L., and Wells, E. (2021). *Understanding multifunctional Bay of Fundy dykelands and tidal wetlands using ecosystem services—a baseline.* FACETS 6: 1446–1473. doi:10.1139/facets-2020-0073
[185] UNESCO. (2022). Landscape of Grand Pré. Retrieved from https://whc.unesco.org/en/list/1404/

Figure 1.46 Starrs Point Dyke in Nova Scotia (Casey OLaughlin)

Figure 1.47 Aboiteau (Emma Poirier)

The former marshland is isolated from sediment-laden tidal flow and is at a much lower elevation than the foreshore marsh (salt marsh in front of dyke) due to subsidence, thus increasing its vulnerability to flooding. In addition, the traditional aboiteau (one-way tide gate) structure can prevent freshwater flood discharge during high tide or surge events, which can cause significant freshwater flooding in the low-lying areas behind the dykes, as has been repeatedly experienced in the town of Truro, NS.[186] It is estimated that flooding of the Chignecto Isthmus, the transportation corridor (rail, Trans-Canada highway) along the border between Nova Scotia and New Brunswick, would halt more than $50 million of trade per day.[187]

[186] Ibid.
[187] Webster, T. & Pett, B. (2012). *An Evaluation of Flood Risk to Infrastructure Across the Chignecto Isthmus* [PowerPoint slides]. Retrieved from http://atlanticadaptation.ca/sites/discoveryspace.upei.ca.acasa/files/A%20Webster%20PettSECURED.pdf

With a mandate to protect agricultural land, the Nova Scotia Department of Agriculture (NSDA) management decisions in the past have been focused on traditional hard infrastructure solutions to reinforce existing dykes and infrastructure, or “hold the line”. However, in recent years, NSDA has begun the process of managing dykelands differently, and has recently undertaken an initiative that will have proponents assessing not only traditional engineering solutions but potential nature-based solutions, when determining feasible design options for dykeland system upgrades. As part of this approach, TransCoastal Adaptations: Centre for Nature-Based Solutions was commissioned to develop a Tidal Wetland Restoration and Dyke Realignment Decision Tool as part of a larger *Dykeland Decision Tool (DDT).*[188] Dyke realignment, the process of removing or relocating agricultural dykes, can result in the restoration of tidal wetland habitat, increased coastal protection by way of natural processes, and reduced maintenance costs for infrastructure. Determining the feasibility of managed (dyke) realignment at a given location requires a holistic view of the landscape – including geotechnical, biological, hydrological, and ecological parameters. This new approach will ensure that the design option that is chosen will have the greatest impact on the landscape as a whole and that decisions are being made based on the best available science and engineering plus factor in climate adaptation options where feasible.[189] The selection of options requires extensive consultation (Figure 1.48) with the involvement of multiple levels of government and many stakeholder groups and individuals.[190,191]

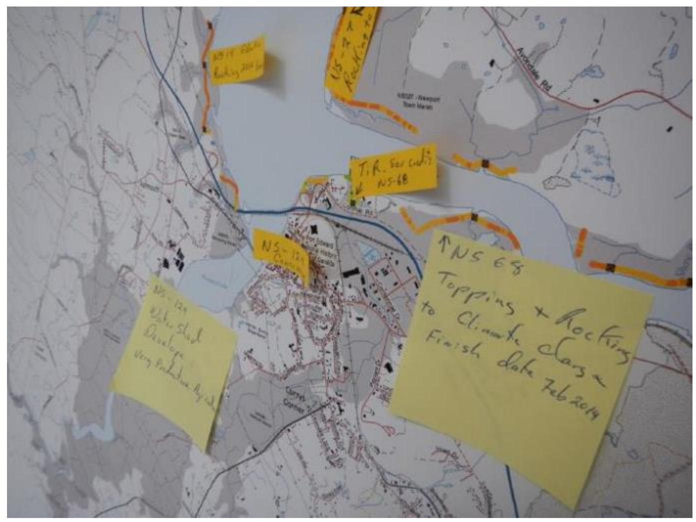

Figure 1.48 Workshop discussion notes (Danika van Proosdij, Saint Mary’s University)

[188] van Proosdij, D., Graham, J., McFadden, C., and Kickbush, J. (2021). *Modelled Approach and Considerations for Tidal Wetland Restoration and Dyke Realignment.* Final report and Excel based tool submitted to Nova Scotia Department of Agriculture, 103 pp.
[189] Ibid.
[190] van Proosdij, D. (2013). *Vulnerability assessment and analysis of options for climate change adaptation in NS68 Tregothic Marsh bodies.* Final report submitted to NS Environment Climate Change Directorate, 46 pp.
[191] van Proosdij, D., Graham, J., Bowron, T., Neatt, N., MacIsaac, B., & Wrathall, C. (2014). *Development and Application of Managed Realignment to Maximize Ecosystem Services and Climate Change Adaptation.* Final report prepared for Environment Canada Gulf of Maine Program. 101 pp.