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ATLANTIC-QUEBEC COST-BENEFIT ANALYSIS OF ADAPTATION OPTIONS IN COASTAL AREAS

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ATLANTIC-QUEBEC COST-BENEFIT ANALYSIS OF ADAPTATION OPTIONS IN COASTAL AREAS: SYNTHESIS REPORT

This Synthesis Report is part of a research project conducted in Quebec and the Atlantic Provinces. The project was managed by:

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This Synthesis Report is based on the results of the research project which comprises eleven (11) case studies that led to the production of the following reports:

STUDY SITE		Report Reference
Quebec	Percé	Circé, M., Da Silva, L., Mercier, X., Boyer-Villemaire, U., Desjarlais, C. and Morneau, F. (2016) Cost-benefit analysis of coastal adaptation options in Percé. Ouranos, Montreal. 155 pages and appendices (Report also available in French).
	Maria	Circé, M., Da Silva, L. Mercier, X., Boyer-Villemaire, U., Desjarlais, C. and Morneau F. (2016) Cost-benefit analysis of coastal adaptation options in Maria. Ouranos, Montreal. 154 pages and appendices (Report also available in French).
	Carleton-sur-Mer	Circé, M., Da Silva, L., Mercier, X., Duff, G., Boyer-Villemaire, U., Corbeil, S., Desjarlais, C. and Morneau F. (2016) Analyse coûts-avantages des options d'adaptation en zone côtière à Carleton-sur-Mer. Ouranos, Montréal. 169 pages et annexes (Executive summary available in English).
	Îles-de-la-Madeleine	Circé, M., Da Silva, L., Duff, G., Boyer-Villemaire, U., Corbeil, S., Desjarlais, C. et Morneau F. (2016) Analyse coûts-avantages des options d'adaptation en zone côtière aux Îles-de-la-Madeleine. Ouranos, Montréal. 174 pages et annexes (Executive summary available in English).
	Kamouraska	Circé, M., Da Silva, L., Duff, G., Boyer-Villemaire, U., Desjarlais, C. et Morneau, F. (2016) Analyse coûts-avantages des options d'adaptation en zone côtière à Rivière-Ouelle. Ouranos, Montréal. 69 pages et annexes (Executive summary available in English).
	Synthesis	Circé, M., Da Silva, L., Boyer-Villemaire, U., Duff, G., Desjarlais, C. and Morneau, F. (2016) Cost-Benefit Analysis for Adaptation Option in Quebec's Coastal Areas – Synthesis Report. Ouranos, Montréal. 89 pages and appendices (Report also available in French).

STUDY SITE		Report Reference
Atlantic Provinces	Chignecto Isthmus	Dietz, S. and Hoyt, J. (2015) Cost-benefit Analysis of Climate Change Adaptation Options for the Chignecto Transportation Corridor. Atlantic Climate Adaptation Solutions Association, 27 pages.
	Halifax Harbour	Walmsey, D. and MacDonald, S. (2015) A Cost Benefit Approach to Selecting Climate Adaptation Options for Management of Halifax Harbour Transportation Infrastructure. Atlantic Climate Adaptation Solutions Association, 20 pages and appendices.
	Prince Edward Island	Parnham, H. (2015) Cost Benefit Analysis of the Risk of Coastal Flooding and Erosion on Infrastructure and Properties in Prince Edward Island. Atlantic Climate Adaptation Solutions Association, 36 pages and appendices.
	Newfound-land	Parnham, H. (2015) Cost Benefit Analysis of the Risk of Coastal Flooding Infrastructure and Properties in Newfoundland and Labrador. Atlantic Climate Adaptation Solutions Association, 46 pages and appendices.
	Synthesis	Parnham, H. and Arnold, S. (eds.) (2015) Using Cost-Benefit Analysis to Evaluate Climate Change Adaptation Options in Atlantic Canada. Atlantic Climate Adaptation Solutions Association, 93 pages and appendices.

The completion of this research project involved many stakeholders and collaborators who contributed to the five case studies. They have had a significant role in this project and their contribution is acknowledged within the individual case study reports. We extend our appreciation to Hope Parnham and Stephanie Arnold, who produced the Atlantic Canada Synthesis Report, the main findings and conclusions of which are part of this report.

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For more information about impacts and adaptation to climate change, please visit www.adaptation.rncan.gc.ca, www.ouranos.ca and www.upei.ca/climate.

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1. INTRODUCTION

1.1 CONTEXT

Historically, Eastern Canada was developed around coastal settlement and activities. However, infrastructure and property in Eastern Canada are increasingly forced to withstand extreme weather events at an unprecedented frequency, more climate variability, and changes in climate norms, all of which threatens the integrity of coastal areas. In fact, coastal areas are particularly vulnerable to climate-driven hazards such as erosion and flooding.

While climate change and its impacts have been studied for some time, research to analyze the vulnerability of communities and infrastructure to such impacts, identify suitable adaptation options, and estimate the damage resulting from climate change has only recently begun in Eastern Canada.

Knowledge of the economics of climate change adaptation is still rudimentary. Most of the literature about adaptation in Canada is in its early stages and focuses on the economic impacts at the national or sectoral levels. Only recently have the regional economic impacts been emphasized, and very few studies addressed the costs and benefits of adaptation options. Most quantified the economic cost of climate change impacts without looking at adaptation. This has been a gap in the research to date, and the private and public sectors currently have no tested protocol to follow when prioritizing the adaptation options available to them.

A detailed appraisal of the economic advantage of implementing coastal adaptation options in Canada is therefore needed in order to assess the viability of adaptation and support investment decisions. Cost-benefit analysis (CBA) is a commonly used economic tool for decision-makers facing a range of alternatives. When applied to climate change adaptation, CBA compares the cost of implementing an adaptation strategy (e.g. armouring a shoreline) and its impacts (e.g. economic losses, change in use value), against the benefits of the loss mitigated (e.g. projected damage to property and infrastructure).

In this context, the Economics Working Group of Canada's Climate Change Adaptation Platform launched a program of work that aimed to create economic knowledge and tools to help decision-makers in Canada's private and public sectors make better adaptation investment choices and policy decisions. Under this program of work, the research project *Economic Assessment of the Impacts of Climate Change and Cost-Benefit Analysis of Adaptation Options,* targeted Quebec coastal areas and the Atlantic Provinces. The work in Quebec was carried out by Ouranos, while the Climate Research Lab of the University of Prince Edward Island coordinated the work in the Atlantic Provinces.

The main objective of the project was to determine the economic viability of various adaptation options in protecting the coastline. In Quebec and Prince Edward Island, the project also included a general assessment of the expected damages due to coastal erosion over the next 50 years (Bernatchez et al., 2015).The current report aims to synthesize the results of the analysis and generalize key learnings from the Quebec and Atlantic Provinces cost-benefit analysis case studies.

1.2 CASE STUDIES

The coastal areas affected by climate change impacts are numerous and diverse. To allow for robust analysis, 11 case study sites were selected across Quebec and the Atlantic Provinces covering various infrastructures and economic sectors, including transportation, trade, fisheries, tourism, residential areas and agriculture. Table 1.1 provides the list of selected case study sites and identifies their key characteristics. The following figure indicates the location of these 11 sites.

Table 1.1 Quebec and Atlantic Case Study Sites and Key Characteristics

Area	Case Study Site	Key Characteristics
Quebec	1- Percé (PER)	Small town and a major regional tourism hub
	2- Maria (MAR)	Small town offering regional health services
	3- Carleton-sur-Mer (CAR)	Small town offering regional educational services and tourist attractions
	4- Îles-de-la-Madeleine (IDM)	Insular town with an economy reliant on tourism and fishery activities
	5- Kamouraska (KAM)	Agricultural area protected by dykes
Atlantic Provinces	6- Chignecto Isthmus (CHI) in New Brunswick and Nova Scotia	Multimodal transportation corridor
	7- Halifax Harbour (HFX) in Nova Scotia	International harbour and multimodal transportation hub
	8- North Cape Coastal Drive and Provincial Park (NCD) in Prince Edward Island	Regional tourism area
	9- Tracadie Small Craft Harbour and Road (THB) in Prince Edward Island	Regional sheltered harbour
	10- Bay Bulls-Witless Bay (BB) in Newfoundland	Harbours and fisheries/industrial facilities
	11- Marystown (MT) in Newfoundland	Harbours and fisheries/industrial facilities

Note: For various reasons, some case study sites in the Atlantic Provinces were not divided into smaller segments for the purposes of the cost-benefit analyses. This is the case of Chignecto Isthmus (CHI), North Cape Coastal Drive and Provincial Park (NCD), and Tracadie Small Craft Harbour and Road (THB). These CBAs were conducted at a broad regional scale.

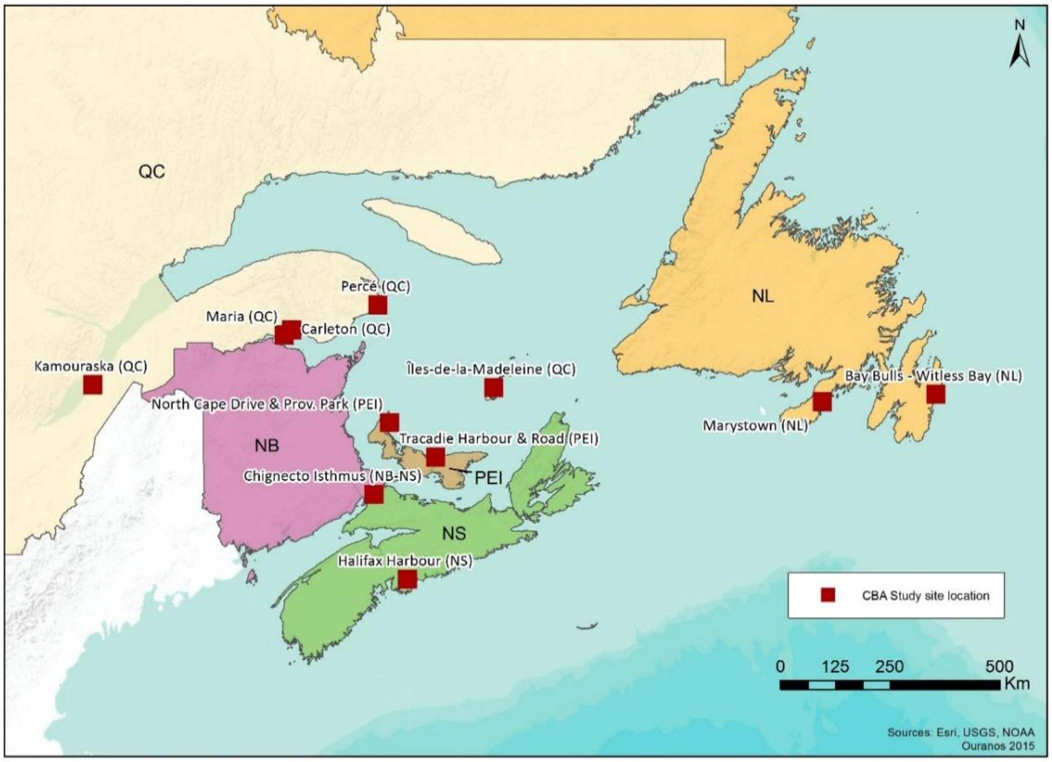


Figure 1.1 Location of Case Study Sites

Most of the 11 case study sites were subdivided into smaller segments in order to analyze coastal areas that are more homogeneous in terms of the type of coastal adaptation options that can be envisaged to adequately protect the assets at risk over the next 50 years (2015–2064). In total, 46 coastal segments were studied, and these are listed and used as units of analysis to compare CBA results in Chapter 4.

1.3 ADAPTATION OPTIONS

The adaptation options that were evaluated were dictated by projected climate change impacts on the specific case study areas as well as the types of coast requiring protection. These adaptation options can be broken down into three categories, as follows:

Hard engineering structures: Seawall, sheet pile wall, dyke, rocky armour or rubblemound revetment, riprap, T groynes or water breakers and mixed combinations of the above.

Soft engineering structures: Beach nourishment or replenishment with or without groynes, bioengineering, trust or toe blocks.

Options without coastal structures: Planned retreat or relocation, accommodation or flood proofing (buildings, roads or dykes), a combination of planned retreat and flood proofing as well as closing down assets (abandonment).

Appendix A outlines all the adaptation options evaluated for each of the 46 segments. The cost-benefit analysis compared all these options to the non-intervention option[1] to determine if it was more advantageous to intervene and, if so, how decision-makers can best intervene from an economic point of view.

1.4 OBJECTIVES

The purpose of conducting the project through 11 case study sites was twofold.

First, each case study analysis provides an inventory of infrastructure, properties and assets jeopardized by the impacts of coastal flooding and/or coastal erosion within the next 50 years; a portfolio of potential adaptation options to address these projected risks; and an assessment of these options based on their costs and benefits.

Second, the outcome of the project provides an assessment of the methodology in different contexts. The 11 case study sites span a wide range of coasts and climate change impacts, as well as varying types of economic drivers. The application of the analysis is generally consistent enough to demonstrate the versatility of the CBA methodology. The lessons learned from comparing and contrasting the 46 segments provide economists and decision-makers with an overview of the benefits and limitations of using CBA to address climate change adaptation from an economic perspective.

In summary, the study objectives were as follows:

1. To build on existing climate change impact and adaptation work along the Quebec and Atlantic coastline relating to sea-level rise, coastal flooding, coastal erosion and infrastructure and property vulnerability by adding an economic layer of analysis;

2. To quantify the economic costs of potential damage to Quebec and Atlantic coastal infrastructure and property subject to future climate changes and to evaluate the economic costs and benefits of appropriate adaptation options;

3. To quantify and compare the net present value (NPV) and benefit-cost ratio (B/C ratio) of adaptation options for Quebec and Atlantic coastal infrastructure and assets under a changing climate;

[1] The non-intervention option was defined differently in each case study. In general, it was intended to minimize intervention as much as possible, leaving the hazards (erosion and/or flooding) to modify the coastline and damage the assets at risk. In other instances, the non-intervention option is a "business as usual" scenario, where a minimal level of intervention was considered.

4. To develop regional knowledge and skills in both the public (e.g. local planners, port authorities) and private (e.g. homeowners, fishers, seaport terminal operators) sectors in the application of CBA to climate change adaptation options in order to strengthen the economic competitiveness of communities and livelihoods; and

5. To develop approaches/methods for building the economic knowledge and tools necessary to help decision-makers make better adaptation investment choices and policy decisions that can be applied elsewhere (regionally, nationally).

1.5 REPORT STRUCTURE

After this introduction, Chapter 2 reviews the key assumptions and the methodological approaches used to develop the erosion and flooding projections, while Chapter 3 focuses on the key economic assumptions and the cost-benefit analysis methodology. Chapter 4 then compares the results of the cost-benefit analysis completed for the 46 coastal segments from different angles, including in terms of the non-intervention option costs, the most advantageous measures, and the key factors that affect NPVs and B/C ratios. Finally, Chapter 5 presents the main lessons learned, followed by the conclusions.

2. CLIMATE CHANGE AND HAZARDS PROJECTIONS

The project's key assumptions relative to climate change and hazards projections concern sea-level rise, flooding and erosion assessment.

For sea-level rise, the RCP 8.5 scenario from the *Fifth Assessment Report* by the Intergovernmental Panel on Climate Change (IPCC) was selected, assuming a constant increase in greenhouse gases until 2100 (IPCC, 2013). Although it is the most extreme scenario from the IPCC and may appear to overestimate sea-level rise, this choice is based on the current scientific consensus on the underestimation of the sea-level increase in the 21st century (e.g. Horton et al., 2014).

For the erosion hazard, the historical rates derived from aerial and terrestrial measurements of coastline retreat were linearly projected in the future. The length of time series differs from one site to another. Linear projection of historical rates may underestimate future erosion rates. It is expected that progress in forecasting the impacts of higher temperatures on ice cover, the freeze and thaw cycles and storm patterns will help to produce more precise erosion rate projections in the future.

For the flooding hazard, water level return periods were used to project the extent of flooding. This approach assumes that land at an altitude lower than the water level is instantly flooded (bathtub hypothesis). This approach also assumes constant terrestrial fluxes (constant runoff/river discharge). A key difference between the Atlantic and Quebec approaches is the inclusion of runup when calculating water levels in Quebec. The inclusion of runup increases the extent of flooding as well as the potential flood damages. A key limit regarding the runup calculation is the availability of reliable wave series and field measurements of past damages levels for calibration.

3. ECONOMIC ANALYSIS METHODOLOGY

The purpose of this project was to compare various adaptation options to the non-intervention option in order to determine whether it is preferable to intervene and which option would be the most economically beneficial, considering the costs and benefits of each option.

A cost-benefit analysis (CBA) was used to compare the total net benefits of each adaptation option for society as a whole. This method has been widely used, notably by different levels of government, for several decades and its modalities are well known to users (Penning-Rowsell et al., 2013). The CBA made it possible to compare different adaptation options over time on a common basis using net present value (NPV) and benefit-cost ratio (B/C ratio) as indicators. The options studied can also be ranked in terms of their economic performance.

The basic assumptions of the CBA, common to all segments, are:

- A time horizon of 50 years, from 2015 to 2064;
- A discount rate of 4% with sensitivity analyses at 2% and 6%;
- Estimates in 2012 Canadian dollars;
- Reference to economic costs, not financial costs;
- Inclusion of study, construction and maintenance costs in the calculation of adaptation option costs.

A key difference between the Atlantic and Quebec economic approaches is the range of costs and benefits which were estimated. While the Atlantic studies estimated only the costs for impacts on infrastructure, assets and major economic activities, the Quebec studies also factored in the costs and benefits for impacts on environmental and social assets as well as for certain other economic activities. Table 3.1 summarizes the costs and benefits estimated in both Quebec and the Atlantic Provinces as well as in Quebec only.

Table 3.1 Range of Costs and Benefits Considered in CBAs

Type or source of costs and benefits	Costs originating from negative impacts	Benefits originating from positive impacts
Related to erosion	- Loss of land	
	- Complete or partial loss of residential or commercial buildings	
	- Loss or damage to public infrastructure	
	- Emergency evacuation	
Related to flooding	- Damage to land	
	- Damage to residential or commercial buildings	
	- Damage to public infrastructure	
	- Emergency evacuation	
	- Traffic congestion or detour	
	- Debris clean-up	
Economic	- Reduced land value	
	- Loss of goods and commercial revenues	
	- Loss of trade	
	- Loss of tourism revenues	- Gain in tourism revenues
Environmental	- Loss of natural habitats	- Improvement in fish spawning grounds
	- Loss of fish spawning grounds	
Social	- Loss of sea view	- Improvement in the coast's recreational use
	- Loss of sea access	
	- Decline in the coast's recreational use	- Improvement in quality of life (security)
	- Reduced quality of life (anxiety, insecurity, etc.)	
	- Deterioration in the landscape	- Improvement in the landscape
	- Deterioration in historical and cultural heritage	

(dark red)	Cost included by Atlantic + Quebec	(light pink)	Cost included by Quebec only	(light green)	Benefit included by Quebec only

The economic approaches applied in Quebec and the Atlantic Provinces were both based on consultations with stakeholders. Stakeholders helped identify the potential impacts of erosion and flooding hazards, select the adaptation options to be assessed, estimate the costs and benefits of adaptation options, and quantify potential impacts. The support of stakeholders increased the robustness of the results and led them to appropriate the results.

In Quebec, field consultations were also carried out by surveying residents and tourists in order to quantify and estimate the use value of six coastal segments. In addition, a provincial survey of 2,000 Quebec residents was conducted over the Internet to determine the potential impacts of specific adaptation options on their tourism behavior in one of the studied segments (Anse du Sud – Percé). As a result, Quebec case studies include costs and benefits on coastal recreational use that cannot be compared to the estimates of the Atlantic case studies.

4. INTEGRATED FINDINGS

This chapter first presents the net present value (NPV) of the non-intervention option for the 46 coastal segments, globally and per linear meter. Then the NPVs of the most advantageous options for the various segments are compared, and the results are broken down into five categories. Finally, the CBA results for each of the five categories are further analyzed to identify the key drivers of the NPVs in each group.

4.1 NET PRESENT VALUE OF NON-INTERVENTION

Table 4.1 and Figure 4.1 present a synthesis of the NPV (discounted at 4%) of the non-intervention option for each segment, over the 50-year study period. The non-intervention option is the baseline scenario for comparing adaptation options, as it represents the costs associated with damages from erosion and/or flooding when intervention is minimal (i.e. due to security, health or legal obligations).

The non-intervention option triggers net costs that range from $0 to $705 million depending on the studied segment. The mean net costs reach $26.4 million while the median is $1 million, indicating that some segments have very high non-intervention costs. Expressed by linear meter of coastline for a better appreciation of site importance, non-intervention costs range from $0 to $777,848, centered on a median of $1,221.

The top five segments in terms of potential damages due to erosion and/or flooding are: Anse du Sud (Percé), Halifax Rail System (Halifax Harbour), Chignecto Isthmus (CHI), Dartmouth Rail System (Halifax Harbour) and La Grave (IDM). The linear cost reveals the importance of linear damages for Pointe-Verte Ouest (Maria) and Rock Harbour Road (MT), while it reduces the importance of damages for the Chignecto Isthmus site due to its length (38 km).

Table 4.1 Net Present Value of the Non-intervention Option by Segment

Segment and site	Non-intervention 4% NPV	Non-intervention per m of coastline
Anse du Sud – PER	($704,601,113)	($776,848)
Halifax Rail System – HFX	($197,137,191)	($34,525)
Chignecto Isthmus – CHI	($124,106,407)	($3,266)
Dartmouth Rail System – HFX	($50,321,868)	($31,451)
La Grave – IDM	($40,138,113)	($38,706)
Kiewit Fabrication Site – MT	($16,928,218)	($4,885)
Centre-ville – IDM	($13,384,935)	($6,187)
Camping du Gros-Cap – IDM	($11,224,910)	($6,473)
Échouerie Ouest – IDM	($6,961,240)	($15,133)
Plage municipale – CAR	($6,101,372)	($6,226)
Banc St-Omer Ouest – CAR	($5,879,100)	($1,183)
Rock Harbour Road – MT	($5,874,026)	($26,107)
Pointe-Verte Ouest – MAR	($4,539,606)	($31,093)
Maria Centre-Ouest – MAR	($4,506,541)	($7,316)
Pédoncule – CAR	($3,246,207)	($3,149)
Coastal Drive and Park – NCD	($2,381,922)	($272)
Harbour Authority Wharf and Breakwater – BB	($1,970,593)	($4,783)
Grande-Entrée – IDM	($1,714,948)	($1,311)
Caps de Maria – CAR	($1,537,995)	($305)
Maria Centre-Est – MAR	($1,390,054)	($3,639)
Fishermen's Cove – HFX	($1,256,445)	($1,056)
Tracadie Wharf and Road – THB	($1,053,792)	($166)
Barry Group Crab Processing Plant – BB	($966,438)	($2,550)
Pointe-Verte Est – MAR	($865,232)	($2,537)
Banc St-Omer Centre – CAR	($723,894)	($1,345)
Rivière-Ouelle – KAM	($619,571)	($146)
Côte Surprise – PER	($559,819)	($403)
Plage municipale – IDM	($434,792)	($1,260)
O'Brien's Whale and Bird Tours – BB	($431,800)	($4,362)
Anse du Nord – PER	($420,147)	($1,012)
Route municipale – IDM	($393,830)	($313)
Ruisseau de l'Éperlan – CAR	($298,294)	($262)
Mont-Joli Sud – PER	($209,467)	($346)
Rue Berthelot – CAR	($195,990)	($685)
Mullowney's Whale Tours – BB	($161,949)	($3,856)
Banc St-Omer Est – CAR	($158,781)	($160)
Gros-Cap Est – IDM	($98,033)	($545)
Water Street Road – HFX	($91,893)	($184)
Witless Bay Ecotours – BB	($35,569)	($214)
Kiewit Shipbuilding site – MT	($7,916)	($14)

Segment and site	Non-intervention 4% NPV	Non-intervention per m of coastline
Bay Bulls Marine Terminal (Pennecon) – BB	($3,594)	($4)
Old Mill Road and Residences – MT	($391)	($1)
Harbour Authority Wharf – MT	($88)	(0)
Lower Road (to Mullowney's) – BB	$0	$0
Lower Road (to Harbour Authority Wharf) – BB	$0	$0
Little Bay Road – MT	$0	$0
Range	**($0–$705 M)**	**($0-776,848)**
Mean	**($26.4 M)**	**($22,265)**
SD	**$107.9 M**	**$114,169**
Median	**($1.0 M)**	**($1,221)**

PER: Percé; MAR: Maria; CAR: Carleton-sur-Mer; IDM: Îles-de-la-Madeleine; KAM: Kamouraska; CHI: Chignecto; HFX: Halifax; NCD: North Coastal Drive; THB: Tracadie Harbour; BB: Bay-Bulls/Witless Bay; MT: Marystown.

Note the lack of damages for four segments in Newfoundland: Lower Road (to Mullowney's, Bay Bulls), Lower Road (to Harbour Authority Wharf, Bay Bulls), Little Bay Road (MT), and Harbour Authority Wharf (MT). Although these segments were found to be vulnerable to flooding, no potential damages were identified during the study period (2015–2064). This result may be attributable to the fact that indirect impacts on road traffic and fishing activities were not considered.

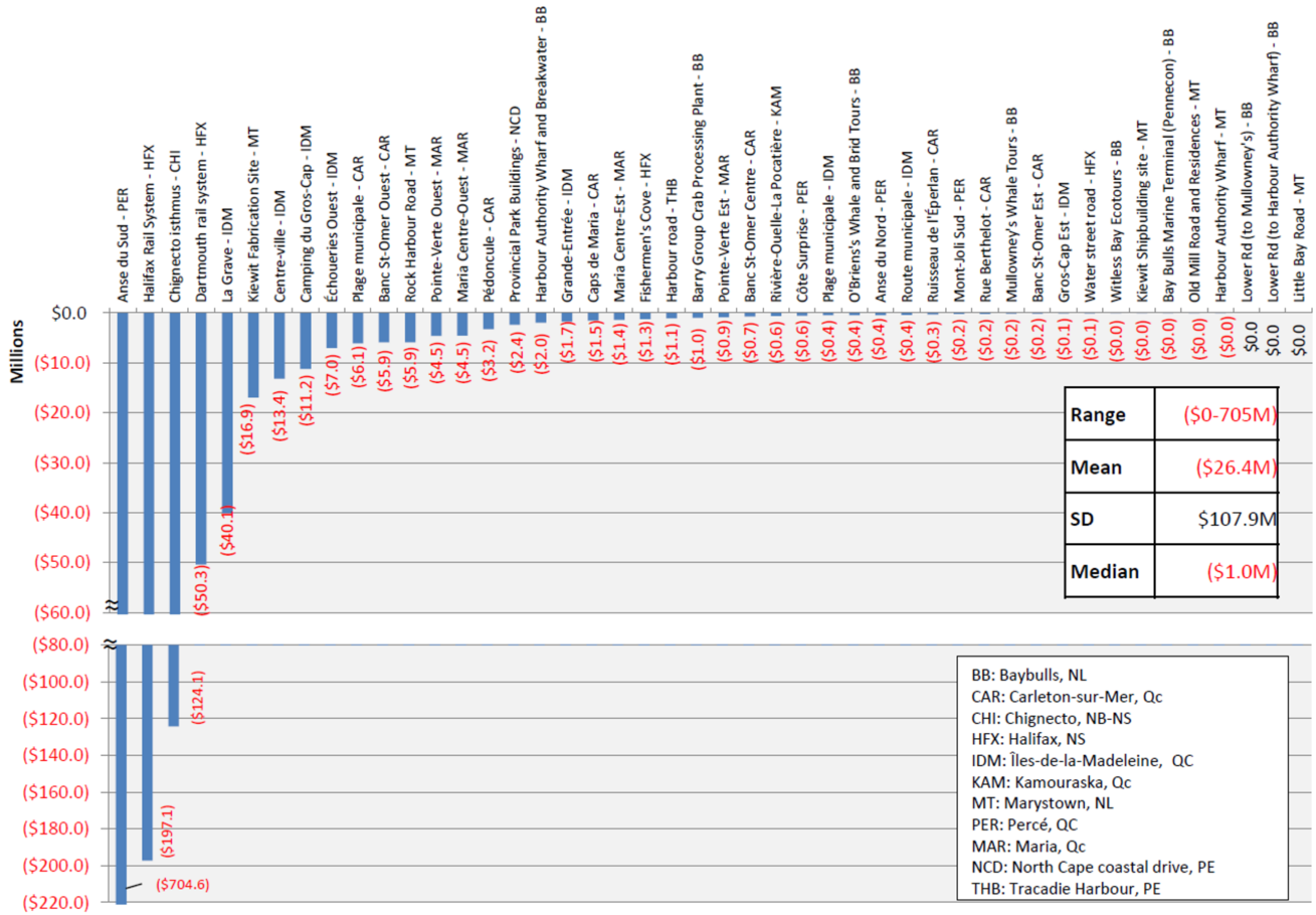


Figure 4.1 Net Present Value of the Non-Intervention Option by Segment

4.2 MOST ADVANTAGEOUS ADAPTATION OPTIONS

The NPVs (4%) of the most advantageous adaptation options were compared to the NVPs for the non-intervention option in each segment. The results are presented in Table 4.2 in order of importance, from the highest comparative NPV to the lowest. Table 4.2 also presents the corresponding benefit-cost ratios, an indicator that is more sensitive to the relative cost of implementing an option than the NPV. In fact, the NPV is mainly driven by the potential benefits for society. Figures 4.2 and 4.3 illustrate the results visually.

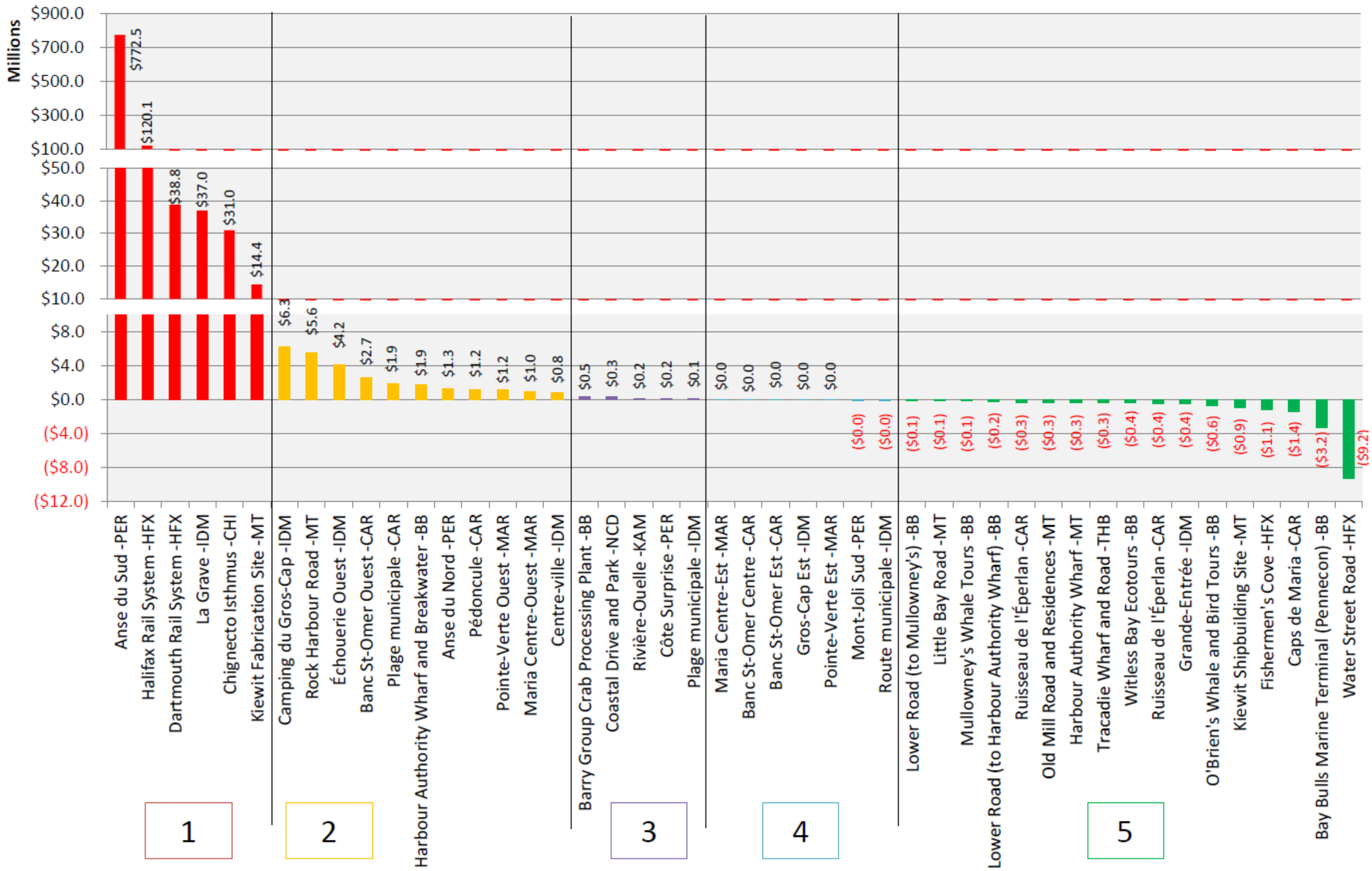
Table 4.2 NPVs of the Most Advantageous Options Compared to the NVP of the Non-Intervention Option by Segment and Corresponding Benefit-Cost Ratios

Segment	Most advantageous adaptation option	Advantage over NI (4% NPVs)	B/C ratio of most advantageous option
Anse du Sud -PER	BN	$772,504,733	68.44
Halifax Rail System -HFX	HE	$120,070,576	2.56
Dartmouth Rail System -HFX	FP	$38,787,584	4.36
La Grave -IDM	BN	$37,035,761	25.78
Chignecto Isthmus -CHI	HE	$31,006,407	1.45
Kiewit Fabrication Site -MT	SW	$14,440,538	6.80
Camping du Gros-Cap -IDM	RR	$6,287,928	4.55
Rock Harbour Road -MT	FP	$5,586,986	20.46
Échouerie Ouest -IDM	RR	$4,227,590	2.55
Banc St-Omer Ouest -CAR	BN	$2,655,426	2.06
Plage municipale -CAR	FP	$1,896,467	1.68
Harbour Authority Wharf and Breakwater -BB	FP	$1,874,913	20.60
Anse du Nord -PER	BN	$1,299,299	1.62
Pédoncule -CAR	BNG	$1,242,650	1.63
Pointe-Verte Ouest -MAR	BNG	$1,216,670	1.41
Maria Centre-Ouest -MAR	FPPR	$1,033,960	3.64
Centre-ville -IDM	RR	$592,307	1.05
Barry Group Crab Processing Plant -BB	SW	$468,902	1.94
Coastal Drive and Park -NCD	CDA	$341,268	1.17
Rivière-Ouelle-KAM	FPPR	$189,308	1.40
Côte Surprise -PER	PR	$158,833	1.40
Plage municipale -IDM	PR	$147,561	1.73
Maria Centre-Est -MAR	FPPR	$23,415	1.15
Banc St-Omer Centre -CAR	FPPR	$20,600	1.78

Segment	Most advantageous adaptation option	Advantage over NI (4% NPVs)	B/C ratio of most advantageous option
Banc St-Omer Est -CAR	PR	$17,646	1.17
Gros-Cap Est -IDM	PR	$17,585	1.29
Pointe-Verte Est -MAR	FPPR	$12,494	1.22
Mont-Joli Sud -PER	PR	($7,255)	0.96
Route municipale -IDM	PR	($10,426)	0.97
Lower Road (to Mullowney's) -BB	FP	($95,680)	0.00
Little Bay Road -MT	FP	($105,248)	0.00
Mullowney's Whale Tours -BB	HE	($105,955)	0.60
Lower Road (to Harbour Authority Wharf) -BB	FP	($191,360)	0.00
Ruisseau de l'Éperlan -CAR	PR	($256,671)	0.49
Old Mill Road and Residences -MT	SW	($286,649)	0.00
Harbour Authority Wharf -MT	SW	($286,952)	0.00
Tracadie Wharf and Road -THB	HE	($325,728)	0.76
Witless Bay Ecotours -BB	SW	($366,287)	0.09
Rue Berthelot -CAR	PR	($415,420)	0.29
Grande-Entrée -IDM	FPPR	($430,258)	0.55
O'Brien's Whale and Bird Tours -BB	FP	($601,544)	0.42
Kiewit ShipbuildingSite -MT	SW	($853,204)	0.01
Fishermen's Cove -HFX	FP	($1,095,288)	0.53
Caps de Maria -CAR	PR	($1,365,118)	0.49
Bay Bulls Marine Terminal (Pennecon) -BB	FP	($3,249,526)	0.00
Water Street Road -HFX	HE	($9,201,077)	0.01

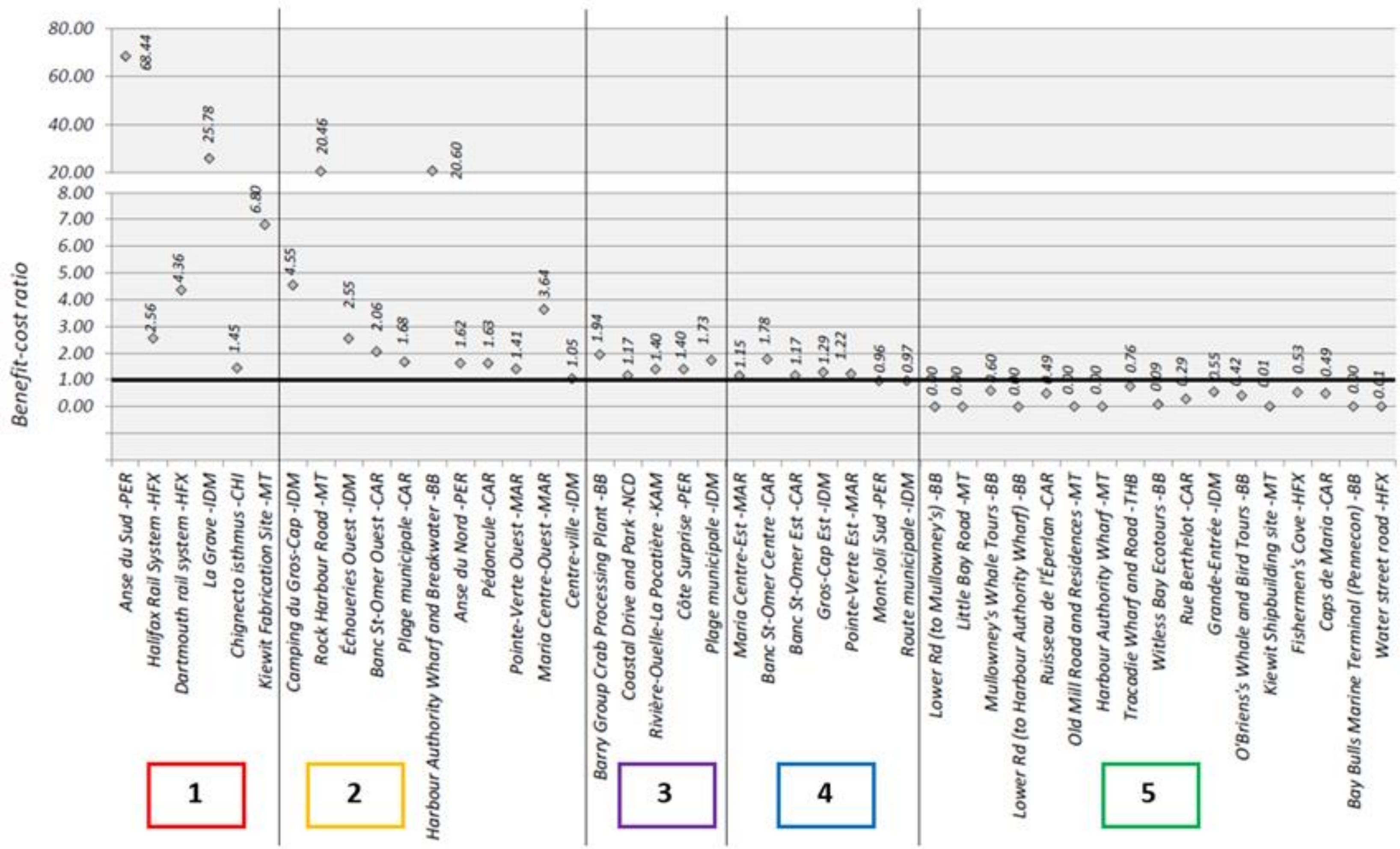
Hard engineering: HE: Mixed hard engineering; RA: Rocky armour or rubblemound revetment; RR: Riprap; SW: Seawall; Soft engineering: BN: Beach nourishment; BNG: BN + Groynes; Options without coastal structures: PR: Planned retreat for buildings and agricultural dyke; FP: Flood proofing by elevation of buildings, roads, agricultural dyke; FPPR: FP + PR; CDA=Close down the asset.

Based on the NPVs compared to the non-intervention option, the results indicate that implementing an adaptation option would generate a net advantage for 29 of the 46 sites (63%) (Figure 4.2; Table 4.2). Based on this metric, the study sites were divided into five groups, each described below: 1) Not intervening is not an option; 2) net advantage to intervene; 3) small advantage to intervene; 4) within a margin of $25,000; and 5) no economic advantage to intervene.



Note: Segment groups: Red: 1-Not intervening is not an option; Yellow: 2-Net advantage to intervene ($0.5 M-$10 M); Purple: 3-Small advantage (<$0.5 M); Blue: 4-Within a margin of $25,000; Green: 5-No economic advantage to intervene

Figure 4.2 NPV of the Most Advantageous Options Compared to the NPV of Non-intervention by Segment



Note: Segment groups: Red: 1-Not intervening is not an option; Yellow: 2-Net advantage to intervene ($0.5 M-$10 M); Purple: 3-Small advantage (<$0.5 M); Blue: 4-Within a margin of $25,000; Green: 5-No economic advantage to intervene

Figure 4.3 Benefit-Cost Ratio of the Most Advantageous Options

4.2.1 First Group of Segments: Not Intervening Is Not an Option

There are six segments where the NPV of the most advantageous option exceeds the NPV of the non-intervention option by at least $14 million. This leads to the conclusion that failing to intervene would represent a considerable loss for society. These six cases are: Anse du Sud (Percé, QC), the Halifax Rail System and Dartmouth Rail System (Halifax Harbour, NS), La Grave (Îles-de-la-Madeleine, QC), Chignecto Isthmus (NB, NS), and Kiewit Fabrication Site (Bay Bulls / Witless Bay, NL) (see Figure 4.4).

In this first group of segments, the potential cost of erosion and flooding hazards is very high because major assets are at risk: tourism infrastructures, industrial facilities, an international harbour and a multi-modal transport hub. In fact, in most cases, there are strategic regional and provincial assets at stake and adaptation brings benefits that spread beyond the local study sites. As a result, the expected costs of non-intervention for these segments are all above $17.0 million. In most cases, 75% to 100% of this amount is associated with economic losses.

The cost of implementing the most advantageous options in this group varies significantly, ranging from $1.5 million (La Grave) to $77.1 million (Halifax Rail System). The preferred options depend mainly on the type of coast requiring protection:

- Soft engineering structures for recreational beach segments (Anse du Sud and La Grave). Beach nourishment is the most advantageous option as it secures access to the beach and offers direct economic advantages, such as an anticipated increase in tourism revenues.

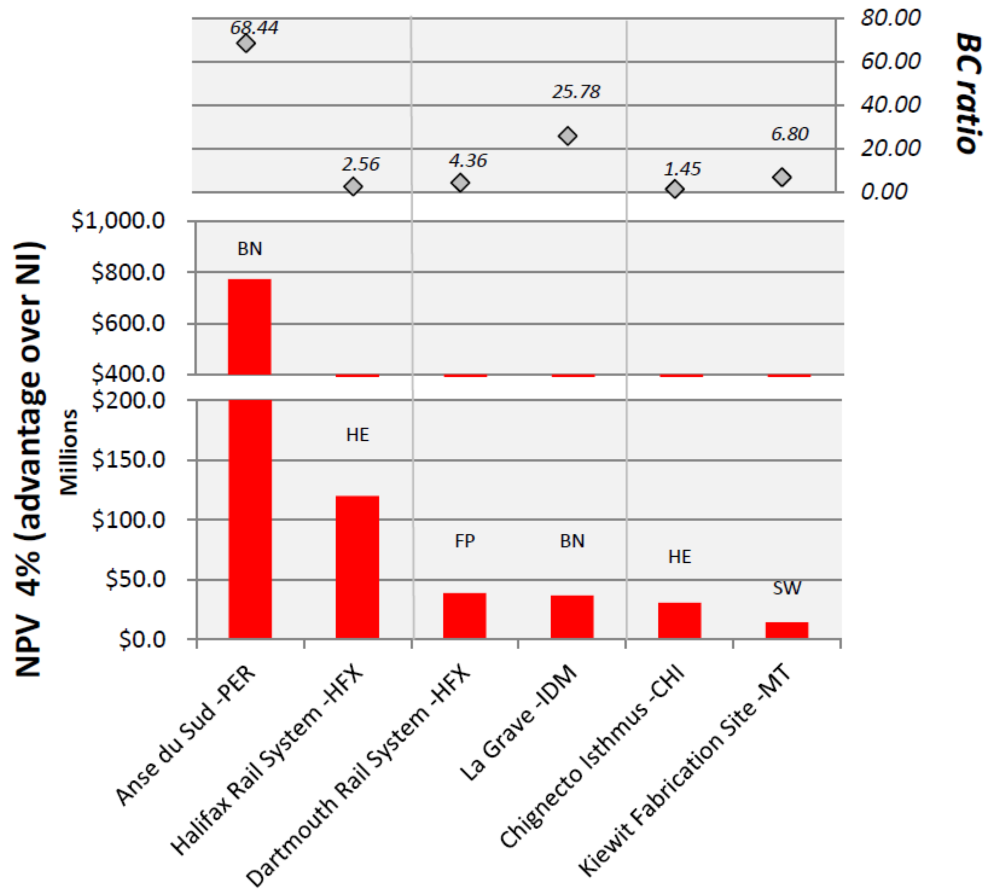
- Hard engineering structures for a multi-modal transportation hub/corridor (Halifax and Dartmouth Rail Systems, Chignecto Isthmus[2]). In order to protect the transportation assets where they are (i.e. in an anthropic environment), hard engineering structures and raising the road base are required. The high implementation cost is offset by the averted damages.

- Hard engineering structures for a highly exposed industrial site: The Kiewit Cow Head Fabrication Facility site in Newfoundland is the province's largest modern offshore fabrication facility. The high damages expected from flooding ($17 million) justify the implementation of a seawall combined with raising the land and road at a cost of $2.5 million.

In terms of benefit-cost ratios, this first group of segments shows a wide range of positive values, from 1.45 (Chignecto) to 68.44 (Anse du Sud). This supports the

[2] The NPV and B/C ratio presented for the Chignecto Isthmus case study come from the Value Added scenario, as selected by the authors of the Atlantic Canada Synthesis Report. Other scenarios which were considered included trade loss estimates of 10 %, 25 % and 100 %. These scenarios lead to a greater cost of non-intervention and higher NPVs and B/C ratios for the adaptation options. However, as the Value Added scenario is already part of the first group - "Not intervening is not an option", using the other scenarios would not change the conclusion.

conclusion that investing in adaptation for these strategic segments maybe beneficial to society.

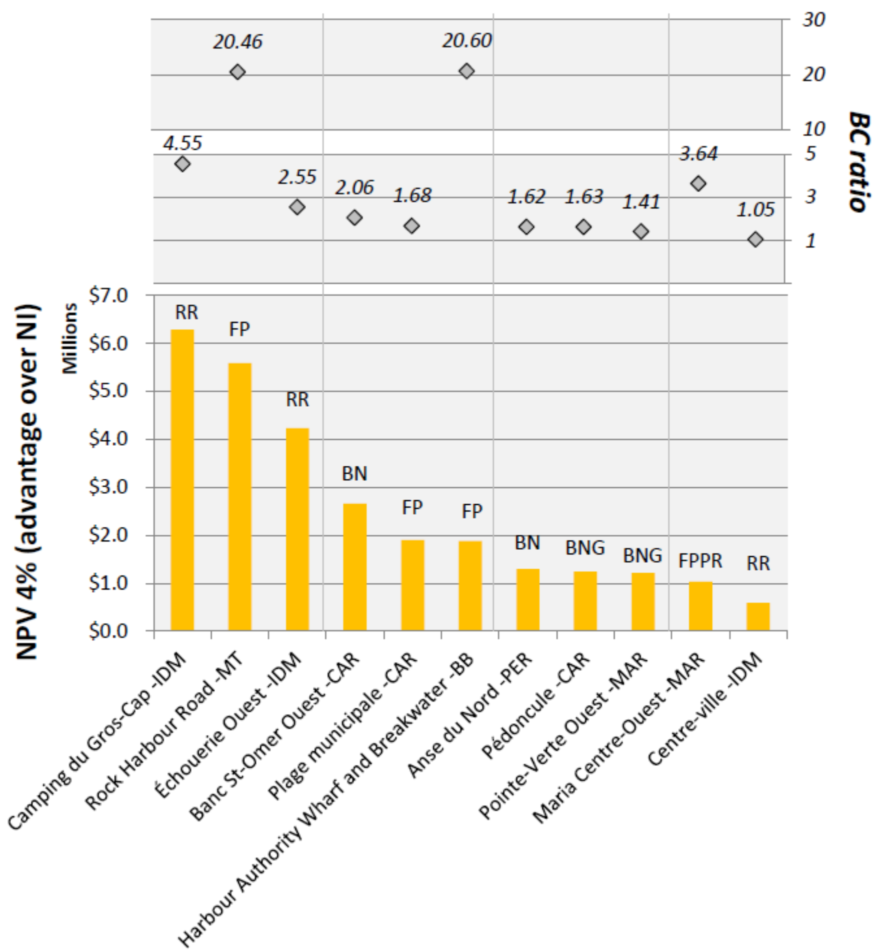


BN: beach nourishment; HE: hard engineering; FP: flood proofing; SW: seawall

Figure 4.4 NPV of the Most Advantageous Options Compared to the NPV of the Non-Intervention Option and Benefit-Cost Ratios for the First Group of Segments

4.2.2 Second Group of Segments: Net Advantage to Intervene

The second group consists of 11 segments that may sustain a high level of damages due to erosion and/or flooding, which would involve an important loss of coastal assets or uses ($0.4 to $13 million). Given the potential impacts, investments in the range of $100,000 to $13 million can be justified economically (see Figure 4.5).



RR: riprap; FP: flood proofing; BN: beach nourishment; FPPR: flood proofing and planned retreat; HE: hard engineering; BNG: beach nourishment + groynes

Figure 4.5 NPV of the Most Advantageous Options Compared to the NPV of the Non-Intervention Option and Benefit-Cost Ratios for the Second Group of Segments

The 11 segments can be divided into three subcategories according to the preferred type of intervention and the type of coast:

- Hard and soft engineering options are impossible or too expensive, despite a relatively high value of assets/uses. This subcategory comprises four segments, two in Quebec and two in Newfoundland. In these cases, a relatively low-cost option like flood proofing and planned retreat is preferred even though it prevents neither erosion nor flooding. The investment cost is a determining factor in selecting an adaptation option.

- Soft engineering structures for low coasts with relatively high asset/use values. The four segments of Banc St-Omer Ouest (Carleton-sur-Mer), Anse du Nord (Percé), Pédoncule (Carleton-sur-Mer) and Pointe-Verte Ouest (Maria) are beach terraces or coastal spit systems where beach nourishment with or without groynes is the most advantageous option (net advantages of $1.2 million to $2.7 million over the non-intervention option). The net advantage of groynes depends on local availability of materials for nourishment maintenance and the number of replenishments required over 50 years.

- Riprap for eroding soft sedimentary cliffs. In three segments in Îles-de-la-Madeleine, Camping du Gros-Cap, Échouerie Ouest and Centre-ville, the value of assets and uses at stake justifies intervention. However, soft engineering structures are not appropriate for this kind of soft sedimentary cliffs. The riprap option offers the best advantage with NPVs of $0.6 million to $6.3 million compared to the NPV of the non-intervention option. In all three cases, the second most advantageous option is planned retreat, which has a higher benefit-cost ratio than that of the riprap option in Échouerie Ouest. However, planned retreat does not minimize damages from erosion as the riprap option does.

Overall, the second group of segments has benefit-cost ratios of over 1. This result confirms that intervention would generate more benefits than costs for society.

4.2.3 Third Group of Segments: Small Advantage to Intervene

The third group of segments shows a small advantage to intervene compared to the non-intervention option, as the NPVs are in the range of a few hundred thousand dollars ($97,000 to $469,000) (see Figure 4.6). These segments typically consist of a single major asset which needs to be protected. The preferred option depends on the type of intervention that can be undertaken in the segment and is always a relatively low-cost option. In four cases, an option without coastal structures is the most advantageous option. The Barry Group Processing Plant segment is the exception, as a hard engineering structure is necessary in this segment to adequately protect the assets.

In the five segments of this third group, all the most advantageous options have a benefit-cost ratio greater than 1. Consequently, intervening to protect single asset scan be advantageous when an appropriate, low-cost adaptation option exists.

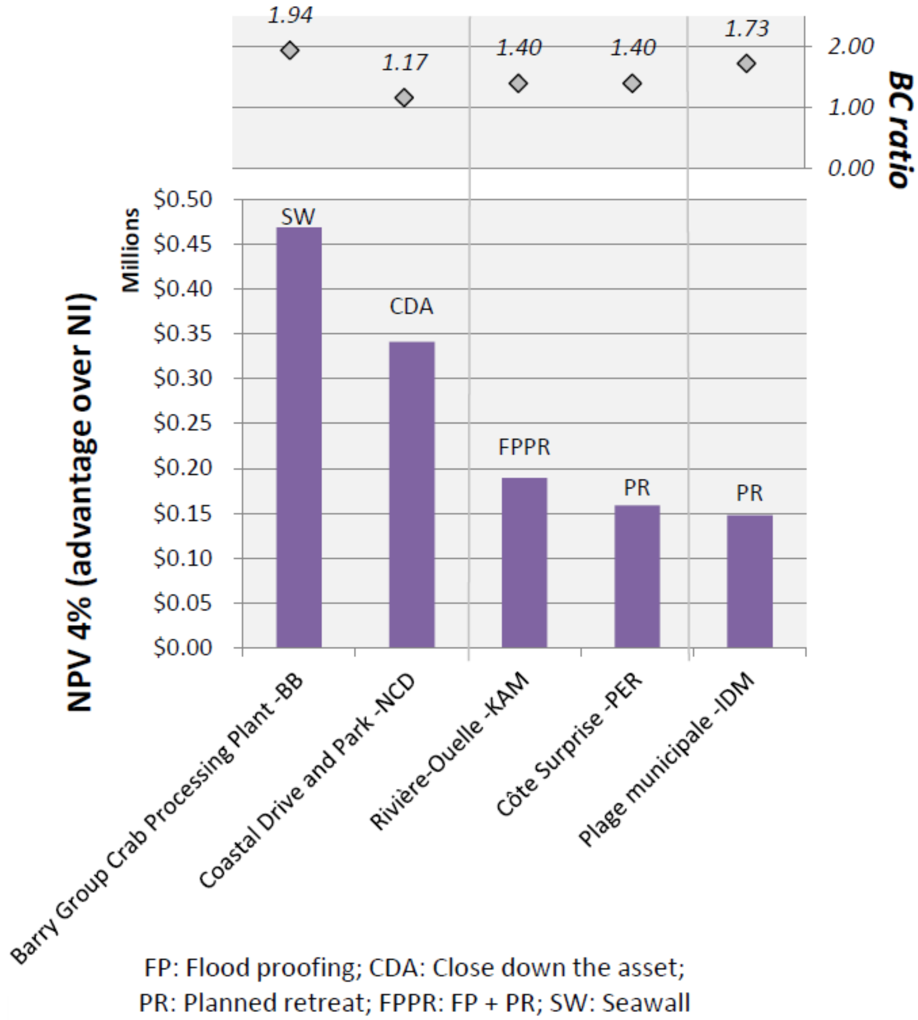


Figure 4.6 NPV of the Most Advantageous Options Compared to the NPV of the Non-Intervention Option and Benefit-Cost Ratios for the Third Group of Segments

4.2.4 Fourth Group of Segments: Within a Margin of $25,000

This group of seven segments involves cases where the difference between the NPV for an option without coastal structures (such as flood proofing, planned retreat or a combination of both) is within a margin of $25,000 of the NVP for the non-intervention option. In five cases, the difference is positive, while it is negative for the other two segments (see Figure 4.7).

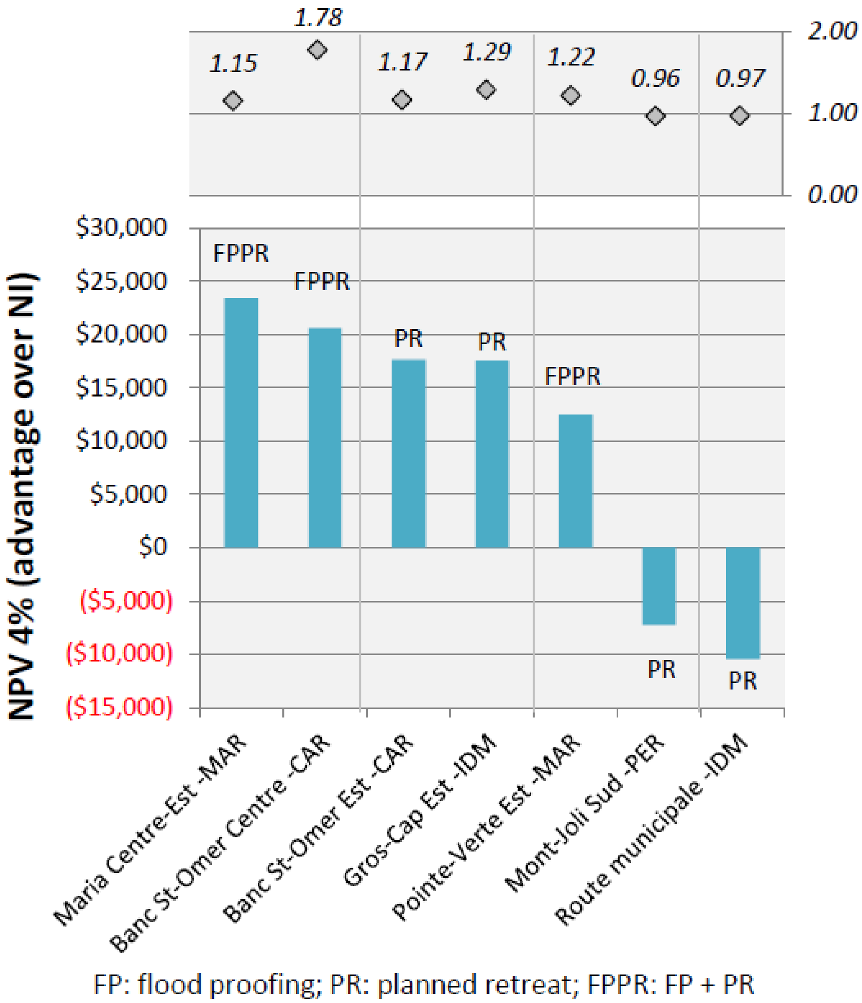


Figure 4.7 NPV of the Most Advantageous Options Compared to the NPV of the Non-Intervention Option and Benefit-Cost Ratios for the Fourth Group of Segments

The segments in this category include Maria Centre-Est (Maria), Banc St-Omer Centre and Est (Carleton-sur-Mer), Gros-Cap Est (IDM), Pointe-Verte Est (Maria), Mont-Joli Sud (Percé) and Route municipale (IDM).

One common factor that may explain the small net advantage or cost is the relatively low damages associated with the non-intervention option. These are estimated at less than $900,000 at 4% over 50 years in six of seven cases, the exception being Maria Centre-Est (MAR), where estimated damages reach $1.4 million. When the potential damages are so low, the discounted cost of the adaptation option must be relatively low to justify an intervention.

The following factors are among those that reduce potential damages:

- Some segments are at risk of erosion but are not threatened by flooding and, on average, damages due to flooding exceed damages due to erosion.
- The assets at risk of erosion are far enough from the coastline to be exposed only at the end of the study period.
- The costs of moving or flood proofing some assets is equal to or higher than the total value of these assets.

When the comparative NPVs are within a margin of $25,000, the results of the CBA are less robust and a change in the economic assumptions can affect them. For example, the inclusion of social costs that could not be accurately monetized in the CBA could modify the results. Some costs whose inclusion may have had a potential effect on results include:

- Maria Centre-Est and Pointe-Verte Est (MAR): Estimating the cost of insecurity among residents whose houses can be hit by wave runup and debris projections during storm events would likely increase the non-intervention cost.
- Mont-Joli Sud (PER): A more reliable estimate for the heritage value of the major asset requiring protection in this segment might have justified intervention.
- Gros-Cap Est (IDM): Estimating the cost of insecurity for residents who live in houses located at the top of a cliff at risk of erosion would likely increase the non-intervention costs.

For this group of segments, the CBA does not provide any strong indicators to assist decision-makers in choosing between intervening or doing nothing. Consequently, the importance of non-economic variables increases in the decision process.

4.2.5 Fifth Group of Segments: No Economic Advantage to Intervene

The fifth and last group consists of 17 segments where there is no economic advantage to intervene. The costs exceed the damages averted through intervention (see Figure 4.8).

First, this category includes six segments where the cost of the non-intervention option is nil or almost nil. In such cases, there is no need to intervene. These segments are Bay Bulls Marine Terminal (BB), Old Mill Road and Residences (MT), Harbour Authority Wharf (MT), Lower Road (to Mullowney's) (BB), Lower Road (to Harbour Authority Wharf) (BB) and Little Bay Road.

For the other segments, all the considered adaptation options are more costly than the averted damages. There are four main cases:

- <u>Moving the assets at risk is more expensive than the total value of these assets.</u> This situation can be found in the segments of Ruisseau de l'Éperlan (CAR), Rue Berthelot (CAR), and Caps de Maria (MAR). Unfortunately the insecurity of living at the top of eroding cliffs was not estimated in the CBA, and this factor would have increased the advantage of intervention.

- Rebuilding hard engineering structures to protect existing infrastructure and assets is not economically justified. This is the case for several segments, including Mullowney's Whale Tours (BB), Witless Bay Ecotours (BB) and the Kiewit Shipbuilding Site (MT).

- Flooding damages are insufficient to justify an intervention to protect wharfs. This situation applies to wharfs at risk in O'Brien's Whale and Bird Tours Wharf (BB), Fishermen's Cove (HFX) and Grande Entrée (IDM). In addition, flooding damages can often be partly averted by temporarily relocating the boats.

- Flooding damages are insufficient to justify an intervention to protect road segments. Damages associated with flooding events in road segments, such as Water Street Road (HFX) and Harbour Road (THB), are too low compared to the cost of flood proofing the roads.

For all 17 segments, the benefit-cost ratio confirms that non-intervention is the preferred option from an economic point of view.

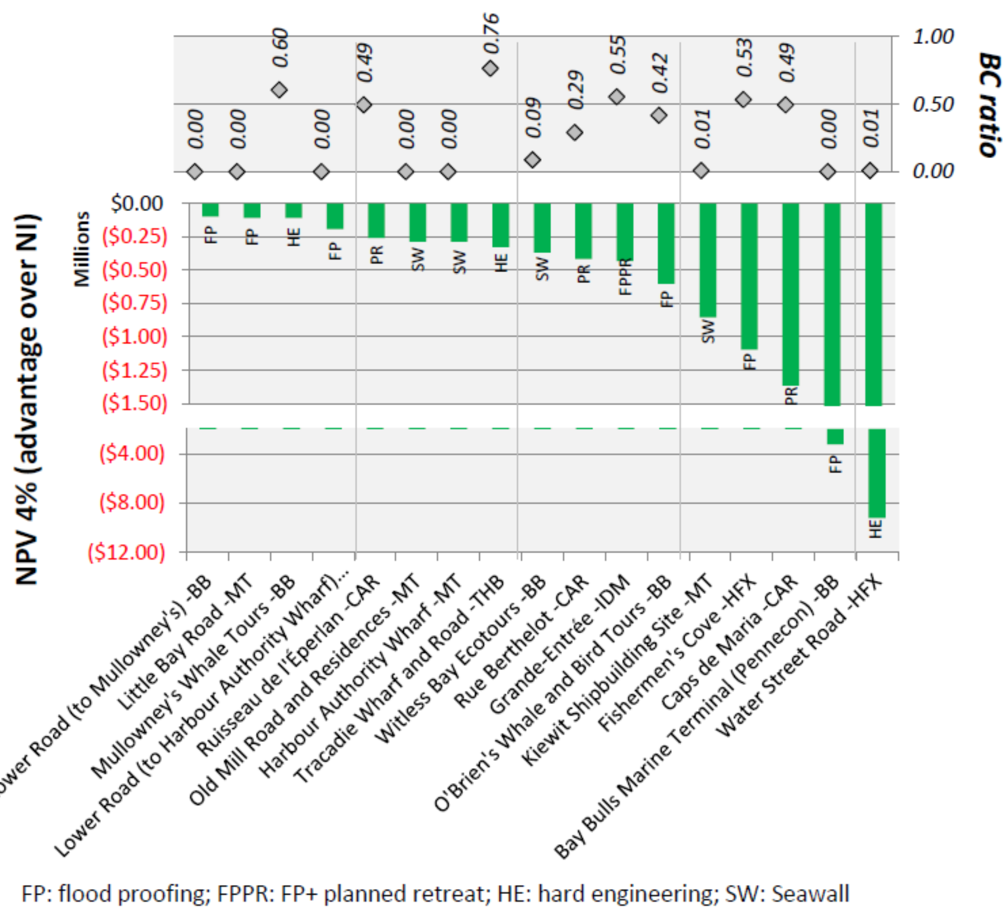


Figure 4.8 NPV of the Least-cost Options Compared to the NPV of the Non-Intervention Option and Benefit-Cost Ratios for the Fifth Group of Segments

5. LESSONS LEARNED

The lessons learned in carrying out the cost-benefit analyses in Quebec and the Atlantic Provinces relate to two main issues: the importance of using a collaborative approach and the factors that enhance the usefulness of the results.

5.1 COLLABORATIVE APPROACH

The CBA process in each case study was supported by strong ties with communities through a collaborative approach. Key public and private asset managers, local and regional authorities, and representatives from various sectors (civil security, transportation, agriculture, environment, etc.) were invited to contribute to the case studies. The process appeared most relevant when stakeholders could be identified at the project's outset.

Over the project's two-year period, dialogue was established, then maintained with stakeholders and collaborators. They were consulted at different stages of the CBA: initially to explore the issues and identify the assets at risk, next to validate the working assumptions and the adaptation options to be assessed, and, finally, to discuss the preliminary results and comment on the reports. This was supplemented by many one-on-one contacts regarding data access. In some cases, this collaboration even led to public meetings to present the results, when requested by municipal stakeholders.

Stakeholder participation in site-specific advisory committees increases access to numerical datasets. When asset managers, the municipality or civil servants were aware of project progress and knew about data gaps they could resolve, many stakeholders expended considerable effort to provide the required data.

Another major benefit of a collaborative approach is to increase acceptance of the results. As indicated in the Atlantic Synthesis report, consensus on adaptation options is rarely spontaneous. In a few of the studies, it was found that different stakeholders had different priorities for adaptation and it was a challenge to combine both public and private interests into a single adaptation scenario for the CBA. In the end, discussions with collaborators revealed the broader complexity of each case study, yielding results that are more robust and thus more likely to be accepted by stakeholders and the population.

Furthermore, stakeholders appeared more likely to defend and use the results when they were actively involved in validating the assumptions and results. In Quebec, local and regional collaborators showed a keen interest in sharing the results within their organizations. Local authorities also requested that the results be presented to the residents of the case study sites. Finally, in the case of Percé, where recent storm events have accelerated the erosion process, the results of the CBA were used by the provincial government to guide the identification of the best adaptation solution.

5.2 FACTORS THAT ENHANCE THE USEFULNESS OF THE RESULTS

The usefulness of the study's results should be optimized given that one of the CBA's major objectives is to support decision-making. The experiences of the project teams show that five key factors enhance the usefulness of the results.

The homogeneity of the studied coastal segments

The spatial segmentation of the sites into segments that are homogeneous in terms of coastal type and adaptation options appears to increase the usefulness of the results. Targeting fine resolution of small-scale coastal segments allows for highly realistic assessment of potential damages. For example, land-registry GIS data along with onsite measurement of building elevation proved to provide reliable and well-accepted estimates of flood and erosion damages.

However, when CBA results are used at a strategic level, in particular for wide-breadth sites, it may not be worthwhile to expend considerable resources to incrementally improve the level of accuracy of the final results.

Completion of a systemic analysis when appropriate

Conducting a systemic analysis appeared essential for segments that are spatially interrelated. In general, such interrelations exist when the segments are part of the same sedimentary unit. In such cases, implementing an adaptation option in a given segment can modify sedimentary transport and the impacts of this change on the other segments must be assessed. For example, because the most advantageous option in Pointe-Verte Ouest (MAR), i.e. beach nourishment with groynes, may modify the sedimentary balance, the impact of this option on segments benefiting from the sedimentary transport should be assessed.

A systemic approach is also useful for analyzing the impacts of erosion and flooding hazards on network infrastructure. A network must be resilient at all points to avoid major disruptions. For example, the Chignecto Isthmus is directly linked to the Halifax Harbour as the latter is the east coast terminus of the trade corridor. Therefore, where networks are involved, a systemic analysis is required to identify vulnerable segments that can jeopardize the whole network.

Broadness of the considered impacts

The CBAs conducted in Quebec and the Atlantic Provinces cover different impacts, as mentioned in Chapter 3. While the Atlantic CBA targeted impacts on infrastructure, public and private assets, and economic activities, the Quebec CBA also assessed the environmental and social impacts (refer to Table 3.1). In fact, in certain cases, considering a broader range of impacts led to selecting options that would not have been considered otherwise. For example, in the Rivière-Ouelle segment (KAM), the environmental benefits of restoring a marsh area exceeded those of protecting agricultural land. Consequently, the most advantageous option involved the partial retreat of the agricultural dyke to recreate a marsh area.

As reported in the Atlantic Synthesis report, the consideration of indirect variables or impacts is key in decision-making processes. Therefore it is preferable to consider as many impacts as possible in order to provide decision-makers with CBA results that take into account all potential interests.

The most appropriate study period

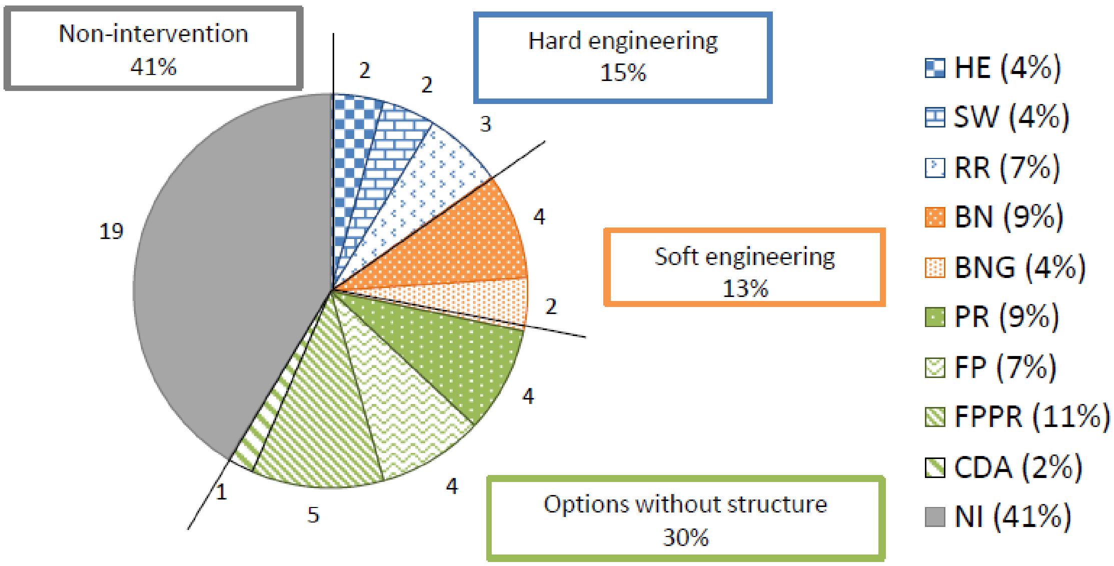
Some of the infrastructure on the case study sites was found to be more resilient to coastal flooding than others, as it had been designed to withstand future coastal flooding. Thus, the study period considered in the CBA should be tailored to the needs of decision-makers. On one hand, infrastructure that is under immediate threat may require quick fixes, with planning for medium- or long-term strategic adaptation approaches. On the other hand, owners of highly resilient infrastructure can focus on long-term sustainable adaptation and make plans that strategically coincide with the maintenance and replacement schedule.

Complementary studies

CBA does not consider the distributive effects of the estimated costs and benefits associated with the most advantageous options. In fact, there is no assessment of those who may gain or those who will likely lose out. As a result, it is difficult for decision-makers to manage the communication of CBA results within the affected communities. Another concern of decision-makers is to know more precisely how much the most advantageous adaptation option will cost in financial terms and how they could finance it. Complementary studies could provide decision-makers with this kind of information and would likely increase the usefulness of CBA results.

6. CONCLUSION

Among the 46 studied segments, implementing a coastal adaptation measure is clearly advantageous for society in 48% of cases. Adding the five segments with a positive NPV of less than $25,000 raises the percentage of intervention to 59%. Close to a third of the most advantageous options are options which do not require coastal structures (i.e. flood proofing, planned retreat or both). Hard and soft engineering structures represent 15% and 13% of the most advantageous options respectively (see Figure 6.1). Finally, the non-intervention option is preferred in 41% of cases.



Legend: HE: Mixed Hard Engineering; SW: Seawall; RR: Riprap; BN: Beach Nourishment; BNG: Beach Nourishment with Groynes; PR: Planned Retreat; FP: Flood Proofing; FPPR: Planned Retreat and Flood Proofing; Close down the asset; NI: Non-Intervention

Figure 6.1 Distribution of the Most Advantageous Options among the 46 Segments

The choice of the most advantageous option depends on many factors such as the type of coast, existing protections, coastal hazards, assets at risk, value of expected damages, indirect costs (environmental and social), and the implementation cost of the considered adaptation options. As such, caution is required when attempting to apply the results of one site to another.

Also, the most advantageous option is not always the least costly, according to CBA results for the 35 segments where several options were compared. An analysis of these results indicates that the most advantageous option is the least costly to implement in 71% of cases. In the other 29% of cases, the most advantageous option is often hard or soft engineering structures, which tend to be relatively costly to implement.

These results indicate that the decision of whether or not to intervene and the selection of the most advantageous option cannot simply be extrapolated for other coastal segments. The importance of the specific characteristics of a study site does not allow for generalizations.

Concerning the five groups of segments identified in this report, their key features are presented in Table 6.1. In summary, the key conclusions for each group are as follows:

- When the potential cost of erosion and flooding hazards is very high because strategic regional or provincial assets are at risk, not intervening is not an option. The benefit for society can even be enhanced by selecting an adaptation option that offers advantages in addition to the averted damages (first group – red).
- When the potential damages associated with erosion and flooding hazards are relatively high, the type of coast and the implementation cost can dictate the choice of the most advantageous option (second group – yellow).
- When the net advantage to intervene is relatively small, the choice of the adaptation option depends on the type of intervention that can be undertaken and the cost of the options, with low-cost options being preferred (third group – purple).
- When the potential cost of erosion and flooding hazards is low, options without coastal structures are preferred but non-intervention is an alternative option, in particular when the value of the assets at risk is relatively low (fourth group – blue).
- Even though the expected damages can be significant, an intervention is not advantageous for society when the value of the assets requiring protection is lower than the intervention cost (fifth group – green).

Table 6.1 Key Features of the Five Groups of Segments

Group of segments	NPV of most advantageous option compared to non-intervention NPV	Non-intervention cost per m of coast (NPV 4%)	Implementation cost of most advantageous options	Group features Type of coast/hazards – assets -options
1-Not intervening is not an option (6 segments)	>$14.0M	$3,000–$777,000	$2.5M–$77M	• Regional/provincial assets at risk (tourism infrastructure, transportation hub/corridor, industrial facilities, etc.). • Direct advantages when the adaptation options can contribute to improving the use of the coast. • All intervention are more beneficial than the non-intervention.
2- Net advantage to intervene (11 segments)	$0.5M–$14.0M	$1,000–$31,000	$0.2M–$13M	• Options without coastal structures (flood proofing and planned retreat) are favoured when hard and soft engineering is impossible or too expensive. • Soft engineering structures are considered the most advantageous options for low coasts with relatively high-value assets/uses. • When the value of assets/uses is relatively high and the coast consists of eroding soft cliffs, riprap is the preferred option.
3- Small advantage to intervene (5 segments)	$25K – $0.5M	$150–$2,500	$154K–$905K	• Segments typically composed of a major asset at risk, such as a commercial building, agricultural land, etc. • The choice of the adaptation option depends on the type of intervention that can be undertaken and the cost of the options, with low-cost options being preferred.
4-Within a margin of $25,000 (7 segments)	($25K) – $25K	$160–$3,700	$29K–$422K	• Option without coastal structures or non-intervention are favoured in this group • The value of assets at-risk and the anticipated damages of the non-intervention are relatively low. • Factors favouring low non-intervention costs: low building density, little or no flood damages and delayed damages due to erosion.
5-No economic advantage to intervene (17 segments)	<($25K)	$0–$4,400	N/A	• Non-intervention is justified when moving assets is more expensive than the total asset value, when existing protection structures are more expensive to rebuild than the value of the protected assets and when expected hazard damages are very low.

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APPENDIX A

This appendix presents the geomorphological characteristics (type of coast, hazards) and the studied adaptation options (hard engineering structures, soft engineering structures and options without coastal structures) for each of the 11 case study sites divided into 46 segments.

Study site	Segment	Key assets	Dominant coast	Hazards		Hard engineering								Soft engineering				Options without structures			
				ERO	FLO	DK	HE	MP	RA	RR	SPW	SW	TG	BN	BNG	BNBio	BNB	PR	FP	FPPR	CDA
Percé	1-Côte Surprise	Commercial buildings	Sedimentary cliffs	x														x			
	2-Anse du Sud	Regional tourist attraction	Beach terrace	x					x	x				x	x						
	3-Mont-Joli Sud	Heritage and commercial buildings	Sedimentary cliffs	x														x			
	4-Anse du Nord	Recreational site	Beach terrace	x					x	x				x				x			
Maria	5-Maria Centre-Ouest	Commercial and residential buildings, provincial road	Beach terrace	x	x						x									x	
	6-Maria Centre-Est	Residential buildings	Beach terrace	x	x							x		x	x					x	
	7-Pointe-Verte Ouest	Residential buildings	Beach terrace	x	x							x		x	x					x	
	8-Pointe-Verte Est	Residential buildings	Coastal spit system	x	x		x							x	x					x	
Carleton-sur-Mer	9-Banc de St-Omer Ouest	Recreational site protecting a marsh and residential area	Coastal spit system	x	x									x	x		x			x	
	10-Banc de St-Omer Centre	Residential area	Beach terrace	x	x				x											x	
	11-Banc de St-Omer Est	Residential area	Beach terrace	x	x				x					x	x			x			
	12-Rue Berthelot	Residential area	Soft sedimentary cliffs	x					x									x			
	13-Ruisseau de l'Éperlan	Residential area	Soft sedimentary cliffs	x					x					x	x			x			

ERO: Erosion; FLO: Flooding; Hard engineering:; DK:Dyke; HE: Mixed hard engineering; RA: Rocky armour or rubblemound revetment; RR: Riprap; SPW: Sheet pile wall; SW: Seawall; TG: T-groynes; Soft engineering: BN: Beach nourishment; BNG: BN + Groynes; BNBio: BN + bioengineering; BNB: BN + thrust/toe blocks; Options without coastal structures: PR: Planned retreat for buildings and agricultural dyke; FP: Flood proofing by elevation of buildings, roads, agricultural dyke;
FPPR: FP + PR; CDA: Close down the asset

Study site	Segment	Key assets	Dominant coast	Hazards		Hard engineering								Soft engineering				Options without structures			
				ERO	FLO	DK	HE	MP	RA	RR	SPW	SW	TG	BN	BNG	BNBio	BNB	PR	FP	FPPR	CDA
Carleton-sur-Mer (suite)	14-Plage municipale	Commercial and recreational area	Coastal spit system	x	x			x											x		
	15-Pédoncule	Commercial and recreational area	Coastal spit system	x	x							x		x	x						
	16-Caps de Maria	Residential area	Soft cliffs	x														x			
Îles-de-la-Madeleine	17-La Grave	Regional heritage and recreation site	Tombolo	x	x				x	x				x						x	
	18-Camping Gros-Cap	Commercial activity	Sedimentary cliffs	x					x	x							x				
	19-Gros-Cap Est	Residential area	Beach terrace	x						x							x	x			
	20-Échouerie Ouest	Commercial and industrial area	Sedimentary cliffs	x			x			x								x			
	21-Route municipale	Residential area, seaside road	Sedimentary cliffs	x					x	x								x			
	22-Plage municipale	Recreational site	Beach terrace	x					x	x							x	x			
	23-Centre-ville	Insular downtown	Sedimentary cliffs	x					x	x								x			
	24-Grande-Entrée	Sheltered harbour	Artificial	x	x				x	x					x					x	
Kamouraska	25-Rivière-Ouelle	Dyked agricultural land	Salt marsh	x	x		x						x					x		x	

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FPPR: FP + PR; CDA: Close down the asset

Study site	Segment	Key assets	Dominant coast	Hazards		Hard engineering								Soft engineering				Options without structures			
				ERO	FLO	DK	HE	MP	RA	RR	SPW	SW	TG	BN	BNG	BNBio	BNB	PR	FP	FPPR	CDA
NB-NS	26-Chignecto Isthmus	Multimodal transportation corridor nerve center	Salt mash		x		x											x	x		
Halifax Harbour (NS)	27-Halifax Harbour rail system	International harbour and multimodal hub	Artificial		x		x												x		
	28-Water Street	Road to harbour	Artificial		x		x												x		
	29-Dartmouth Rail System	International harbour and multimodal hub	Artificial		x		x												x		
	30-Fishermen's Cove	Road to harbour	Artificial		x							x							x		
PEI	31-North Cape Coastal Drive and Park	Regional tourist attraction (national park and road)	Sedimentary cliffs	x	x		x		x		x							x			x
	32-Tracadie Wharf and Road	Regional sheltered harbour	Sedimentary cliffs	x	x		x		x									x	x	x	x
Bay Bull / Witless Bay (NL)	33-Bay Bulls Marine Terminal (Pennecon)	Harbour and fisheries/industrial facilities	Artificial		x														x		
	34-O'Briens's Whale and Brid Tours	Wharf and commercial activity	Artificial		x														x		
	35-Mullowney's Whale Tours	Wharf and commercial activity	Artificial		x		x												x		
	36-Lower Road (to Mullowney's)	Road to wharf	Artificial		x														x		

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Study site	Segment	Key assets	Dominant coast	Hazards		Hard engineering								Soft engineering				Options without structures			
				ERO	FLO	DK	HE	MP	RA	RR	SPW	SW	TG	BN	BNG	BNBio	BNB	PR	FP	FPPR	CDA
Bay Bull / Witless Bay (NL)	37-Harbour Authority Wharf and Breakwater	Harbour and fisheries/industrial facilities	Artificial		x				x			x							x		
	38-Lower Road (to Harbour Authority Wharf)	Road to harbour	Artificial		x														x		
	39-Barry Group Crab Processing Plant	Fisheries/industrial facilities	Artificial		x					x		x									
	40-Witless Bay Ecotours	Wharf and commercial activity	Artificial		x							x							x		
Marystown Bay (NL)	41-Kiewit Fabrication Site	Harbour and fisheries/industrial facilities	Artificial		x							x							x		
	42-Kiewit Shipbuilding Site	Harbour and fisheries/industrial facilities	Artificial		x							x							x		
	43-Harbour Authority Wharf	Harbour	Artificial		x							x							x		
	44-Rock Harbour Road	Road to harbour	Artificial		x														x		
	45-Old Mill Road and Residences	Road to harbour	Artificial		x							x									
	46-Little Bay Road	Road to harbour	Artificial		x														x		

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