



$$VAN = \sum_{t=1}^T \frac{avantages_t}{(1+\rho)^t} - \sum_{t=1}^T \frac{coûts_t}{(1+\rho)^t}$$

COST-BENEFIT ANALYSIS OF ADAPTATION OPTIONS IN QUEBEC'S COASTAL AREAS

Synthesis Report
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COST-BENEFIT ANALYSIS OF ADAPTATION OPTIONS IN QUEBEC'S COASTAL AREAS – SYNTHESIS REPORT

PROJECT: ECONOMIC ASSESSMENT OF THE IMPACTS OF CLIMATE CHANGE AND COST-BENEFIT ANALYSIS OF ADAPTATION OPTIONS IN QUEBEC'S COASTAL AREAS

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1. INTRODUCTION

Few studies to date have focused on the economic assessment of climate change impacts and adaptation options in the coastal areas of eastern Quebec. A program of work was therefore initiated by the Economics Working Group of Canada's Climate Change Adaptation Platform, chaired by Natural Resources Canada, 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 coastal areas of Quebec and the Atlantic Provinces.

The Quebec study was conducted by Ouranos and its primary partner, the Laboratoire de dynamique et de gestion intégrée des zones côtières (LDGIZC) of University of Quebec in Rimouski (UQAR). In addition to the support of Natural Resources Canada, this study benefited from funding from the Quebec government's Green Fund under the 2013–2020 Action Plan. In total, 25 coastal segments were subject to cost-benefit analysis (CBA): 16 segments in three municipalities of Gaspésie (Percé, Maria and Carleton-sur-Mer), 8 segments in Îles-de-la-Madeleine and one segment in the Bas Saint-Laurent region, south of the mouth of Ouelle River.

The purpose of this report is to bring together the results of the various CBAs for comparison using the selected economic indicators, that is, the net present value (NPV)

and the cost-benefit ratio (C/B ratio). This document summarizes five case study reports that are available on the Ouranos website (Table 1.1).

Table 1.1 – References for the Cost-Benefit Analysis Reports for Quebec

Study site	Report reference
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. 150 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. et 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).

The second chapter of this report summarizes the methodological approaches used to project coastal erosion and flooding from 2015 to 2064 for every segment under study. The third chapter briefly describes the economic methodology for estimating the costs and benefits of various adaptation options and comparing them to the non-intervention option.

The next five chapters address the coastal segments studied in Percé, Maria, Carleton-sur-Mer, Îles-de-la-Madeleine and Rivière-Ouelle. Each chapter gives a short description of the study area and the coastal segments examined, the adaptation options considered and the CBA results.

Chapter 9 analyzes and compares the results for all 25 coastal segments studied in Quebec as part of the research project. The NPVs and B/C ratios are used as economic

indicators for determining whether it is better to take action to protect the coast than to do nothing.

Chapter 10 looks at the key lessons learned from completing the case studies. These lessons translate to suggested approaches for future studies and research avenues that would refine certain CBA methodology components in coastal environments and provide more relevant findings for decision-makers.

Finally, the conclusion focuses on the key outcomes of this study and the main elements that could help decision-makers make better informed choices for adaptation to climate change in Quebec's coastal areas.



2. METHODOLOGICAL APPROACHES FOR PROJECTING COASTAL HAZARDS

This chapter presents the main methodological choices made to establish projections for coastal erosion and flooding at the five study sites in a context of climate change.

2.1 SEA-LEVEL RISE SCENARIO

The benchmark for the global sea-level rise is the RCP 8.5 emissions scenario from the Fifth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC), where greenhouse gases increase constantly. Although this extreme scenario may appear to overestimate the anticipated rise, its selection is based on recent scientific literature showing that sea-level fluctuations have been underestimated for the 21st century (Horton et al., 2014).

2.2 COASTAL EROSION

Having a wealth of knowledge about erosion and flooding in Quebec's coastal areas, LDGIZC of UQAR developed probable coastal evolution scenarios for each segment of the coast over the study period (2015–2064). The laboratory's scenarios are based on an analysis of historic rates and their variation.

By order of priority, the LDGIZC used the following sources to determine the probable rate of coastal evolution insofar as these data reflected the new climate conditions associated with climate change:

- Data on coastal evolution for the most recent period (2000s);
- Data from the laboratory's coastal erosion monitoring system, consisting of close to 5,000 monitoring markers;
- Historical data on coastal changes;
- Data from an estimated mean by type of coast for a given region.

The laboratory also estimated the potential retreat rates during storm events using data observed by type of coast in a given region. These rates are generally higher than mean annual retreat rates but were not explicitly considered in the calculation of anticipated impacts from erosion, because it is impossible to predict when storm events will occur. Rather, these extreme event retreat rates are taken into account in the probable evolution rates which were determined based on past events.

Table 2.1 presents the probable coastal evolution rates for each segment examined, specifying the type of coast and the length of the segment.

Table 2.1 – Probable Coastal Erosion Rate for Each Segment Examined

Study Site	Segment	Dominant coast	Length of the segment (m)	Probable erosion rate (m)
Percé	Côte Surprise	Sedimentary cliff	1,388	-0.11
	Anse du Sud	Beach terrace	907	-0.08 to -0.13
	Mont-Joli Sud	Sedimentary cliff	605	-0.1
	Anse du Nord	Beach terrace	415	-0.13 to -0.14
Maria	Maria Centre-Ouest	Beach terrace	616	-0.24
	Maria Centre-Est	Beach terrace	382	-0.83
	Pointe-Verte Ouest	Beach terrace	146	-0.76
	Pointe-Verte Est	Littoral spit system	341	0.51
Carleton-sur-Mer	Banc St-Omer Ouest	Littoral spit system	4,971	-1.9
	Banc St-Omer Centre	Beach terrace	538	0.07
	Banc St-Omer Est	Beach terrace	990	-0.72
	Rue Berthelot	Low soft cliffs	286	-0.22
	Ruisseau de l'Éperlan	Low soft cliffs	1,140	-0.35
	Plage municipale	Littoral spit system	980	0.18
	Pédoncule	Littoral spit system	1,031	-0.27
	Caps-de-Maria	Soft cliffs	5,038	-0.69
Îles-de-la-Madeleine	La Grave	Tombolo	440	-0.23
	Camping Gros-Cap	Sedimentary cliff	1,734	-0.37 to -0.82

Study Site	Segment	Dominant coast	Length of the segment (m)	Probable erosion rate (m)
	Gros-Cap Est	Beach terrace	180	-0.45 to -1.0
	Échouerie Ouest	Sedimentary cliff	460	-0.45
	Route municipale	Sedimentary cliff	1,258	-0.38
	Plage municipale	Beach terrace	345	-0.38 to -0.64
	Centre-ville	Sedimentary cliff	2,163	-0.31 to -0.43
	Grande-Entrée	Port area	500	-1.61
Kamouraska	Rivière-Ouelle	Salt marsh protecting an agricultural dike	4,223	+0.3 to -1.9

2.3 COASTAL FLOODING

Flooding episodes that cause damage are the result of extreme water levels and waves that break on the coast and create runup. Return periods for high water levels are expected to be shorter due to the relative sea-level rise and the milder winters.¹ The former is due mainly to the warming oceans (from thermal expansion) due to climate change and the sinking continent (isostatic adjustment). The milder winter weather is expected to reduce the coverage of sea ice, giving waves more room to form over a longer period in the year (Bernatchez et al., 2008).

The general approach is to calculate return periods for flood levels for the current situation as well as for the time horizons of 2030 and 2055 based on the impact of climate change and a series of assumptions concerning:

- the probability of storm surges;
- the probability of waves and associated runup; and
- the joint probability of storm surges and waves.

Table 2.2 presents the relative net sea-level rise (eustatic rise plus isostatic adjustment compared to the period centered on 1995), the winter periods with ice cover (months), the correction factor and the corrected extreme water-level return periods for 2, 10, 30 and 100-year flooding for each study site.

The coastal segments studied in Percé and Cap-aux-Meules (IDM) are not vulnerable to flooding. The data for the east part of Maria and for the Carleton-sur-Mer are drawn from Didier et al. (2014). Data for the western part of Maria, Îles-de-la-Madeleine and Kamouraska were calculated by Ouranos. In Kamouraska, there is no correction factor for joint return periods, even for the winter season, because runup has little impact on flood levels.

¹“Return periods refer to the probability of having an extreme water level occurrence. For example, a 20-year return period means the extreme water level would occur on average once within the next 20 years. Return periods can also be expressed as an annual probability. A 20-year return period has a 5% probability of occurring every year.

Given the short time horizon of the initial data series for waves in Maria and in Carleton-sur-Mer, return periods were calculated up to 30 years, whereas in other sectors, data over 33 years allowed to calculate return periods of up to 100 years.

Table 2.2 – Flooding Assumptions

Site	Maria		Carleton-sur-Mer		Îles-de-la-Madeleine			Kamou-raska
	Ouest	Est	With runup	Without runup	La Grave	GE	GE without runup	
Sea-level rise (cm) current								
- 2030	+4	+4	+4	+4	+10	+10	+10	+2
- 2055	+19	+19	+19	+19	+25	+25	+25	+8
	+40	+40	+40	+40	+50	+50	+50	+22
Months with ice cover	JFMA	JFMA	JFMA	JFMA	JFM	JFM	JFM	N/A
Correction factor for joint return periods	3-10	3-10	3-10	3-10	16,67	16,67	16,67	N/A
Estimated runup for December 2010 (m)	1.2	0.41	0.41	-	1.07	1.07	-	N/A
Estimated maximum water level December 2010 (geodetic m)	3.69	2.90	2.90	2.49	2.24	2.61	1.55	3.93
Corrected total flooding level in 2055 (geodetic m)								
2 years	3.44	2.55	2.55	2.19	2.08	1.96	1.23	3.74
10 years	4.16	3.07	3.07	2.65	2.48	2.43	1.50	3.96
30 years	4.62	3.43	3.43	2.97	2.74	2.73	1.69	4.11
100 years	-	-	-	-	3.02	3.06	1.90	4.27



3. ECONOMIC METHODOLOGY

To conduct a cost-benefit analysis, it is necessary to be familiar with the economic, environmental and social issues of the studied area, as well as to understand how the proposed interventions will impact these issues. During this project, the approach was centered on stakeholder involvement at every step of the study in order to foster the knowledge-sharing essential to the project's relevance.

Four types of committees were established to assist the project team in the analysis: local steering committees, a regional committee, a technical committee, and an advisory committee.

In every municipality targeted in the study, the municipality established a local steering committee of stakeholders, decision-makers, municipal employees, and elected officials to guide study-related work based on local needs and realities. Members of these committees provided invaluable help in obtaining the data used to quantify and monetize the impacts and the costs of adaptation options.

For its part, the regional committee helped identify potential adaptation options and the impacts these options might have on flora, fauna, infrastructure, and economic activities. The preliminary results of all five case studies were also discussed with the regional committee in order to validate certain conclusions. Five provincial ministries were represented on the regional committee: the Ministère de l'Agriculture, des Pêcheries et de l'Alimentation (MAPAQ), the Ministère des Affaires municipales et de l'Occupation du territoire (MAMOT), the Ministère du Développement durable, de l'Environnement et de

la Lutte contre les changements climatiques (MDDELCC), the Ministère de la Culture et des Communications (MCC), and the Ministère des Transport. Representatives of the Department of Fisheries and Oceans sat on this committee.

As for the technical committee, it was composed of coastal specialists, including two coastal engineers, two geomorphologists, an oceanographer, and economists. The committee's primary mandate was to propose adaptation options for each coastal studied segment based on the coastal issues at play.

Finally, an advisory committee brought together coastal and cost-benefit analysis specialists, as well as representatives of the organizations funding the project. This committee validated the project's overall research objectives and the methodology for carrying out the study's different steps.

3.1 ECONOMIC ANALYSIS

The purpose of the study is to compare, in economic terms, the various adaptation options to non-intervention in order to determine whether intervention is preferable and to identify which adaptation option would be most beneficial given the economic, social and environmental costs and benefits.

The cost-benefit analysis was used to achieve this. This method allows for comparison of the total net benefits of each adaptation option from a societal perspective. For decades this method has been widely used in economic analysis, particularly by various levels of government. The methodology is relatively simple, well established and documented, notably in the coastal setting (Penning-Rowsell et al., 2013).

Over a given period, a cost-benefit analysis (CBA) can compare various adaptation options on a common basis using indicators, notably the net present value (NPV) and the benefit-cost ratio (B/C ratio). The options examined can then be ordered based on their economic performance.

To ensure that a consistent framework was used across the study sites (in Quebec and the Atlantic Provinces), common economic parameters were selected for the analysis:

- A 50-year study period (2015–2064);

- A 4% discount rate with sensitivity analyses at 2% and 6%;
- Monetization in 2012 constant dollars.

The CBAs conducted as part of the project involved six key steps: 1) identification of adaptation options; 2) identification of the impacts of adaptation options and non-intervention; 3) monetization of negative impacts (costs) and positive impacts (benefits); 4) estimation of the implementation costs for adaptation options; 5) comparison of the costs and benefits; 6) sensitivity analysis of the results.

3.1.1 Identification of adaptation options

Based on the specific context of the sector examined and input from meetings with the local, regional and technical committees, adaptation options from three categories were selected for the various segments in the study: hard engineering structures, soft engineering structures, and options without coastal structures (Table 3.1). Hard structures are conventional hard engineering structures, like seawalls and rubblemound revetment, which aim to stabilize and harden the shoreline. Soft structures, like beach nourishment (with or without groynes) and vegetated dunes, allow for a certain natural movement of sediments and the shoreline. Options without coastal structures aim to reduce exposure to hazards by protecting assets rather than intervening on the environment. Details on implementation, costs and the technical characteristics of every kind of options are described in the chapters on each case study.

Table 3.1 – Adaptation Options Considered by Segment

Case study	Segments	Dominant coast	Hard structures	Soft structures	Options without coastal structures
Percé	Côte Surprise	Sedimentary cliffs			PR
	Anse du Sud	Beach terrace	CW, RA, RR	BN, BNG	
	Mont-Joli Sud	Sedimentary cliffs			PR
	Anse du Nord	Beach terrace	RA, RR	BN	PR
Maria	Maria Centre-Ouest	Beach terrace	SPW		FPPR
	Maria Centre-Est	Beach terrace	CW	BN, BNG	FPPR
	Pointe-Verte Ouest	Beach terrace	CW	BN, BNG	FPPR
	Pointe-Verte Est	Littoral spit system	DK+CW	BN, BNG	FPPR
Carleton-sur-Mer	Banc de St-Omer Ouest	Littoral spit system		BN, BNG,	FPPR
	Banc St-Omer Centre	Beach terrace	RA		FPPR
	Banc de St-Omer Ouest	Beach terrace	RA	BN, BNG	PR
	Rue Berthelot	Low soft cliffs	RA		PR
	Ruisseau de l'Éperlan	Low soft cliffs	RA	BN, BNG	PR
	Plage municipale	Littoral spit system	HE		FP
	Pédoncule	Littoral spit system	CW	BN, BNG	
	Caps-de-Maria	Soft cliffs			PR
Îles-de-la-Madeleine	La Grave	Tombolo	RA, RR	BN	FPPR
	Camping Gros-Cap	Sedimentary cliffs	RA, RR		PR
	Gros-Cap Est	Beach terrace	RR	BN+toe blocks	PR
	Échouerie Ouest	Sedimentary cliffs	RA, RR		PR
	Route municipale	Sedimentary cliffs	RA, RR		PR, PR+move road
	Plage municipale	Beach terrace	RA, RR	BN+toe blocks	PR
	Centre-ville	Sedimentary cliffs	RA, RR		PR
	Grande-Entrée	Artificial	RA, RR	BNG	FPPR
Rivière-Ouelle (Kamouraska)	Rivière-Ouelle	Salt marsh	TG, RA		Partial retreat, Depolderization

Legend: CW: concrete wall; RR: riprap; DK: dyke; RA: rocky armour or rubblemound revetment; TG: T-groynes; SPW: sheet pile wall; HE: mixed hard engineering; BN: beach nourishment; BNG: BN + groynes; BNBio: BN + bioengineering; PR: planned retreat; FPPR: flood proofing and planned retreat; FP: flood proofing

3.1.2 Identification of the anticipated impacts

The next step is to assess how non-intervention and each adaptation option affect the economic and social environments as well as the natural environment, which is often disturbed by human intervention.

A first group of impacts is that of impacts associated coastal hazards (erosion and flooding). It involves, among other aspects, loss or damage to land and buildings, as well as costs incurred for debris clean-up, emergency measures and evacuation costs. In this study, all such impacts are considered direct impacts and these will be amplified by climate change.

In addition to impacts directly related to erosion and flooding, there are economic, environmental² and social effects. These impacts are wide-ranging and must be determined on a case-by-case basis for each adaptation option and segment. Table 3.2 presents all anticipated positive and negative impacts considered in the case studies.

3.1.3 Monetization of negative and positive impacts

A number of economic evaluation methods were used in this study depending on the nature of the impacts and data availability. Market transactions were privileged in order to monetize impacts. Where no market exists for a given type of impact, indirect evaluation methods were used. These include the hedonic price method and the travel cost method. Thirdly, where no data could be derived from direct or indirect transactions, the monetization of certain impacts required the use of methods based on a hypothetical market such as contingent valuation. In this case, estimations were made using surveys of the individuals concerned, in particular with respect to coastal use. Finally, the results available in the economic literature were used to value certain impacts. This was the case for certain environmental impacts.

² The environmental impacts considered in this study are the medium- and long-term effects of adaptation options on the natural environment. Anticipated impacts during construction are excluded as they are generally too short in duration to significantly affect the NPV. However, the environmental impact studies, the costs of which are factored into the CBA, should take into account these impacts, in accordance with standard practice in the field.

Table 3.2 – Expected Impacts

Type of impact	Negative impacts	Positive impacts
Related to erosion	<ul style="list-style-type: none"> - Loss of land - Complete or partial loss of residential or commercial buildings - Loss or damage to public infrastructure 	
Related to flooding	<ul style="list-style-type: none"> - Damages to land - Damages to residential or commercial buildings - Damage to public infrastructure - Emergency evacuation - Debris clean-up - Traffic congestion or detour 	
Economic	<ul style="list-style-type: none"> - Reduced land value - Loss of goods and commercial revenues - Loss of tourism revenues 	<ul style="list-style-type: none"> - Gain in tourism revenues
Environmental	<ul style="list-style-type: none"> - Loss of natural habitats - Loss of fish spawning grounds 	<ul style="list-style-type: none"> - Improvement in fish spawning grounds
Social	<ul style="list-style-type: none"> - Loss of sea view - Loss of sea access - Decline in the coast's recreational use - Reduced quality of life (anxiety, insecurity, etc.) - Deterioration in the landscape - Deterioration in historical and cultural heritage 	<ul style="list-style-type: none"> - Improvement in the coast's recreational use - Improvement in quality of life (security) - Improvement in the landscape

3.1.4 Estimation of costs to implement adaptation options

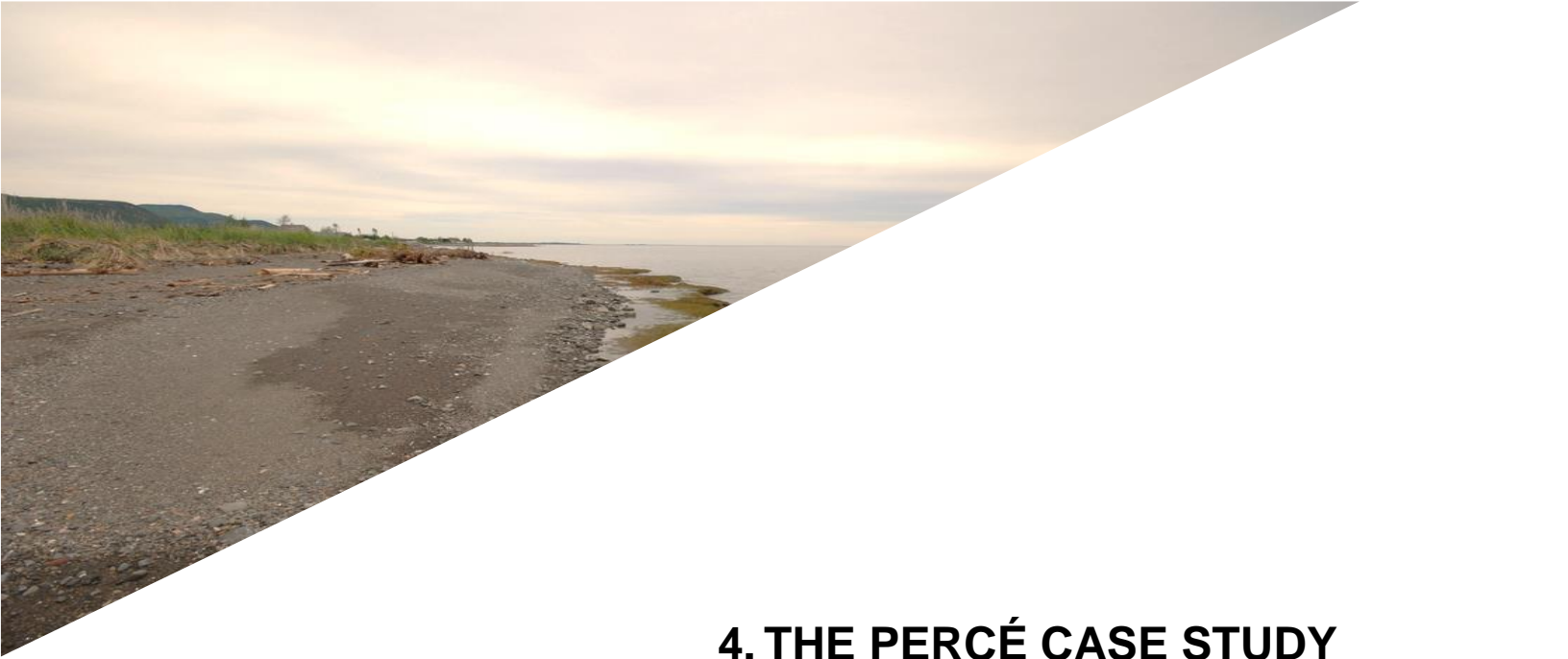
On top of costs associated with anticipated negative impacts, the cost-benefit analysis requires that the implementation and maintenance costs of adaptation options be estimated. In general, these costs are calculated based on the cost incurred during similar projects or by engineers specializing in design of the proposed options. Although these costs are quite easy to estimate because they are based on prior projects, they remain approximate as they were rarely determined through detailed engineering studies for the coastal segment examined.

3.1.5 Comparison of costs and benefits

Once the impacts are quantified and monetized, all costs and benefits for each adaptation option are compared with the costs of non-intervention in order to assess the economic performance of each option. All the costs and benefits for the various adaptation options and for the non-intervention option are discounted at 4 % over the study period (2015-2064). All values are also expressed with a common monetary unit (2012 dollars) in order to eliminate any distortion from inflation. The next chapters describe the results of CBAs conducted for the five case studies.

3.1.6 Sensitivity analysis of results

Sensitivity analysis is an important component of a CBA. It allows for an examination of the robustness of the NPV obtained when important assumptions or parameters of the analysis are modified. The different values considered in the sensitivity analysis aim to reflect the degree of uncertainty associated with each variable. Notably, sensitivity analyses for the discount rate are always carried out using 2% and 6% discount rates. The sensitivity analysis expresses the potential variability of the NPV.



4. THE PERCÉ CASE STUDY

For many years now, Percé has been experiencing serious climate change impacts, due to sea-level rise, milder winters, loss of ice cover on the Gulf of St. Lawrence and changing storm patterns. In particular, the waterfront boardwalk and the building behind it have been subject to repeated damage for several years. It is becoming urgent to implement appropriate measures to protect the coast, notably to maintain tourism traffic.

4.1 STUDY AREA

In the City of Percé, 4 segments of the coast were studied and the limits of these segments are presented in Figure 4.1. These segments are Côte Surprise, Anse du Sud, Mont-Joli Sud and Anse du Nord. They were defined and according to their physical characteristics and land use, in addition to the anticipated risks.



Figure 4.1 – Location of the Study Area and the 4 Segments under Study in Percé

4.2 ADAPTATION OPTIONS

The technical adaptation options studied, in particular the engineering structures, were drawn from the conceptual study conducted by engineering firm BPR (BPR et al., 2014). These options take into account the hydrodynamic conditions, erosion, sedimentation and geotechnical constraints associated with the segments under study. The adaptation options were designed to avoid all problems of erosion over the next 50 years.

Where possible, more than one option was compared to the non-intervention option. However, planned retreat was the only option considered for two segments composed largely of cliffs. Table 4.1 lists the adaptation options studied in each segment.

Table 4.1 – Adaptation Options Considered in each Segment in Percé

Adaptation options	Côte Surprise	Anse du Sud	Mont-Joli Sud	Anse du Nord
Hard engineering structures		Seawall Rubblemound Riprap		Rubblemound Riprap
Soft engineering structures		Beach replenishment Beach replenishment with groynes		Beach replenishment
Options without coastal structures	Planned retreat		Planned retreat	Planned retreat

The main conclusions drawn for each of the four segments are presented below.

4.3 CÔTE SURPRISE

The Côte Surprise segment is located southwest of Percé Bay. It is bounded on the west by the cape Blanc and on the east by the rubblemound that begins in front of the Riôtel Hotel. This part of the coast is composed mostly of over 30-metre-high cliffs of sedimentary rock, which have low resistance to erosion. Remote compared to the center of Percé, this segment has few buildings south of the provincial highway. To the west, there is a motel with three buildings each containing 12 units, a restaurant and a pub. In the middle, there is a campsite with 125 pitches. The eastern part has not been built on or developed.

The major issues in this segment are erosion and the possibility of the upper cliff collapsing. Certainly, active cliffs can recede quickly and unpredictably. If nothing is done in the next 50 years, several business assets will be at risk, including the three Motel La Côte Surprise buildings, as well as some thirty camping pitches.

A loss of business income is to be expected for the region, in addition to the loss of buildings and land. The motel units with a view of Rocher Percé and Bonaventure Island, which will be lost due to erosion, will unlikely be replaced with motel units offering an equally beautiful view. The camping pitches, however, could be easily replaced. The

cost-benefit analysis results indicate that non-intervention in this segment would lead to a negative net present value of close to -\$560,000 over 50 years.

Given the height of the cliffs, only planned retreat is considered as a technically appropriate adaptation option in this segment. This option involves moving at-risk assets to another part of the property if the area is large enough, which is the case for the Motel La Côte Surprise buildings. The buildings should be moved as soon as they are 5 m from the edge of the cliff, to allow for safe manoeuvring of buildings and equipment. The net present value of planned retreat is about -\$401,000. The net discounted benefits of this option total about \$160,000 over 50 years compared to the non-intervention option.

A sensitivity analysis shows that the CBA results are robust to an increase in the value of the at-risk assets, and to a decrease in the estimated value of the view of Rocher Percé and Bonaventure Island from the motel units. Furthermore, introducing a safety margin of 4.3 m to prevent building collapse significantly increases the benefit of planned retreat. Finally, the results of the CBA favour planned retreat when the discount rate is decreased to 2% but not when it is increased to 6%.

Therefore in all cases, unless a discount rate of 6% is used, planned retreat is the most economically viable option over a period of 50 years. The benefit-cost ratio of planned retreat compared to non-intervention is 1.4. Planned retreat would therefore generate benefits equivalent to \$1.40 for every dollar invested by the society.

In the Côte Surprise segment, the buildings that are exposed have an economic value high enough to justify economically their preservation with planned retreat over a 50-year period. Even if certain calculation assumptions are modified, planned retreat remains the least costly option over 50 years.

4.4 ANSE DU SUD

The Anse du Sud segment is the historic, cultural and economic heart of Percé. This coastal segment, between the Riôtel Hotel and Percé wharf, is threatened by the sea waves, which cause tens of thousands of dollars of damage every year. The main portion of the segment (towards the north) is protected by a concrete seawall that supports the seaside boardwalk. In recent years, ad hoc emergency interventions have

helped to hold the wall and boardwalk in place, but the wall is at the end of its useful life and these two infrastructures are extremely vulnerable to storm events.

Without adequate protection, the coastline in the northern part of the segment is expected to be subject to erosion again by 2020 and to retreat by an average of -15 cm per year. Further south, the coast is composed of low rocky cliffs protected by a rubblemound that is in poor condition and poorly calibrated. The observed erosion rate is -8 cm per year despite existing protection.

In the next few years, a number of business and tourism assets in this segment will be at risk. Hotels and businesses will be directly exposed to erosion within the study period (50 years). Moreover, the seaside boardwalk is predicted to disappear, which would put the tourism character of the City of Percé under serious threat. The central axis formed by the boardwalk and wharf attracts 400,000 visitors every year.

An analysis of the potential impacts of non-intervention shows that the wall's inability to protect coastal assets could lead to total discounted losses of nearly \$705 million over 50 years, mostly due to a decline in tourism traffic in the whole of the Gaspésie region. An online survey conducted among 2,000 Quebecers revealed that if the boardwalk were lost, many people would spend less time in the Gaspésie region or would not go there so often. This change of behaviour would result in a 21% decrease in overnight stays in the Gaspésie region, about 320,000 less each year.

Given the scale of these impacts, five adaptation options have been studied to redevelop and protect the Percé coast: building a seawall, constructing a rubblemound, installing a riprap, and beach replenishment with or without groynes³. An analysis of the costs and benefits of each option was conducted, taking into account not only the implementation costs, but also the costs and benefits relating to the economic, environmental and social impacts of implementing these options. The Quebec survey results were used, among other things, to assess how the implementation of each of the five options would affect tourism traffic.

³ See BPR et al., (2014) for the design and characteristics of the adaptation options that require engineering work.

Among the studied options, the most economically advantageous option is beach replenishment with pebbles. It would provide net benefits discounted at 4% of approximately \$773 million over 50 years compared to the non-intervention option (see Figure 4.2). Non-intervention costs (\$705 million) would be avoided and it would generate additional net benefits of \$68 million. These additional gains would come from a 2% increase in tourism, about 35,000 overnight stays each year.

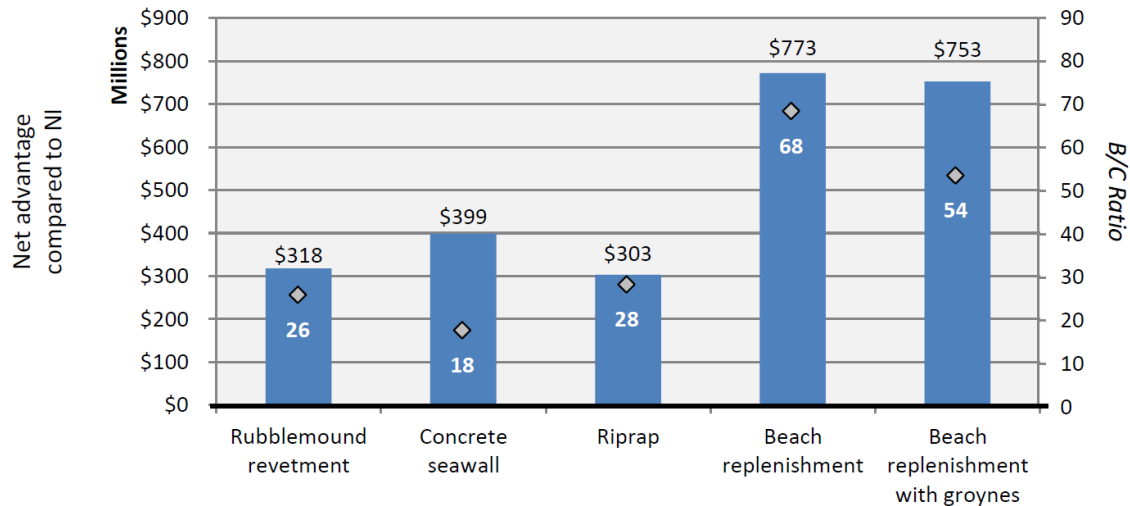


Figure 4.2 – Net Discounted Benefits Compared to the Non-intervention Option and Benefit-cost Ratios in Anse du Sud

Beach replenishment with pebbles also has the highest benefit-cost ratio, with benefits 68 times greater than the costs. So, each dollar invested by the society could generate \$68 in benefits. This result is clearly due to significant tourism benefits and to construction costs lower than those of the other options, even though beach replenishment involves high maintenance costs every 12 years. A steady supply of pebbles is indeed essential to ensure the sustainability of this option in the long term and its ability to protect the infrastructures over the next 50 years.

The second most advantageous adaptation option is beach replenishment with T-groynes, which are rock structures built at right angles to the coast and used to keep pebbles in place. The net discounted benefits of this option are in the order of \$753 million compared to non-intervention. Although more costly than beach

replenishment without groynes, this measure does not require maintenance for the study period. The benefits are 54 times greater than the costs.

Building a new seawall with deflector to better withstand future storm events offers discounted benefits of \$399 million. This measure, like constructing a rubblemound or a riprap⁴, are advantageous options compared to non-intervention, but they would not allow maintaining the tourism traffic at the levels of the last few years in the Gaspésie region. These results bring to light the importance of taking action. Whatever option is implemented, it will always be more advantageous to protect and develop the Anse du Sud coast than to do nothing.

A sensitivity analysis revealed that the results of the cost-benefit analysis are robust to changes in assumptions. A change in the discount rate affects the results but does not alter the order of preference of the adaptation options. With regard to the assumptions on tourism traffic changes, even the most pessimistic forecasts do not alter the ranking of the options. Beach replenishment with pebbles is still the most economically viable option.

In summary, potential losses in the Anse du Sud segment are high, but the potential economic benefits from the implementation of adaptation options are higher, amounting to hundreds of millions of dollars over 50 years. Beach replenishment is the most beneficial adaptation option, followed closely by beach replenishment with T-shaped groynes.

4.5 MONT-JOLI SUD

The third segment, the portion south of the cape Mont-Joli, is an iconic landscape of Percé. It is composed of 12 to 25-metre-high rocky cliffs. Erosion rates are fairly low, varying from - 1 to -10 cm/year, depending on the type of rock. However, some buildings are very near the cliffs and appear to be vulnerable to erosion in the medium to long term. According to erosion rate projections, the Frederick-James Villa, located less than

⁴ Riprap is an adaptation option built by dumping layers of stones of various size with a soft slope in order to absorb and dissipate wave energy before it reaches the shore.

4 m from the edge of the cliff, will be exposed to erosion during the study period. This is a special heritage building in Percé and its presence on Mont-Joli enhances the value of the landscape and view of Rocher Percé.

The non-intervention option in the Mont-Joli South segment would result in a negative NPV of -\$209,470 in 2012 dollars discounted at 4%. This economic loss is essentially the loss of the building's property and heritage value of the Frederick-James Villa totalling over half a million dollars. Discounting plays a major role here, as the building is expected to be lost in 2042 according to the segment's projected erosion rate.

Over a 50-year time horizon and with a discount rate of 4%, the net present values of non-intervention and planned retreat are almost the same. In other words, planned retreat in the Mont-Joli South segment does not appear to be economically preferable to the non-intervention option.

Sensitivity analyses on the heritage value, discount rate and erosion rate were conducted in an effort to make a distinction between the option of non-intervention and that of planned retreat. The sensitivity analyses of the heritage value and erosion rate could not clearly determine which of these two options is more economically beneficial, as the difference between the NPVs of the two options is within the margin of error of the economic analysis. However, a sensitivity analysis combining an increase in the heritage and landscape value of the Frederick-James Villa (20%) and a slight increase in the erosion rate (10%) would favour the planned retreat option compared to non-intervention.

As for variations in the discount rate, the sensitivity analysis showed that the time factor is critical in this segment. Even though the Frederick-James Villa is only at risk in 2042, its preservation would require imminent relocation, as the building is already less than 5 m from the cliff hedge. Therefore, a decision is urgently needed if it is to be preserved for future generations.

4.6 ANSE DU NORD

The fourth segment under study in Percé is Anse du Nord, which covers the area between the capes Mont-Joli and Barré. It is a natural-looking pebble beach, a

complementary site to Anse du Sud in Percé's tourism offering. While much less visited than the Anse du Sud segment, a few thousand visitors come to Anse du Nord every year to walk, swim, fish and admire the view of Rocher Percé. It offers a remarkable natural environment that would benefit from development so its beauty could be fully appreciated.

In terms of erosion, the coast of this segment is eroding more quickly than that of the other segments: the erosion rate is estimated at -18 cm/yr. Given the retreat of the shoreline, non-intervention would lead to the loss of land, residential buildings, hotels and businesses. The value of the losses discounted at 4% would amount to \$420,000 over 50 years.

Four adaptation options been assessed to prevent these losses: constructing a rubblemound, installing a riprap, beach nourishment and planned retreat⁵.

The results of the CBA show that beach replenishment is the only economically viable option compared to the non-intervention option over a 50-year period. Unlike the other adaptation options, beach replenishment could produce benefits by encouraging the recreational use of the coast (\$3.0 million), which amount to more than the cost of the option (\$2.1 million). Over the entire period, beach nourishment would result in benefits of \$1.3 million compared to non-intervention (Figure 4.3). Given the increased recreational use and protection of assets, each dollar invested in beach replenishment by the society would generate benefits of \$1.62.

In comparison, relocating assets would generate a negative net present value of just over -\$100,000 compared to the non-intervention option. This means that non-intervention is preferable to moving at-risk assets in this segment. This is due to the high cost of moving buildings compared to their property assessment value. In the case of planned retreat, each dollar invested would generate benefits of less than one dollar (\$0.77).

⁵ See BPR et al., (2014) for the design and characteristics of the adaptation options that require engineering work.

Providing protection with a riprap, which would cost about the same as beach replenishment, would result in more environmental costs (destruction of capelin spawn) without increasing recreational use value of the coast. With a negative net present benefits and a benefit-cost ratio less than 1, this option is not economically justifiable. Finally, constructing a rubblemound would constitute the least economically viable option compared to non-intervention (-\$4.0 million) because it is costly to implement (\$4.4 million) and does not provide indirect benefits such as improved recreational use of the coast.

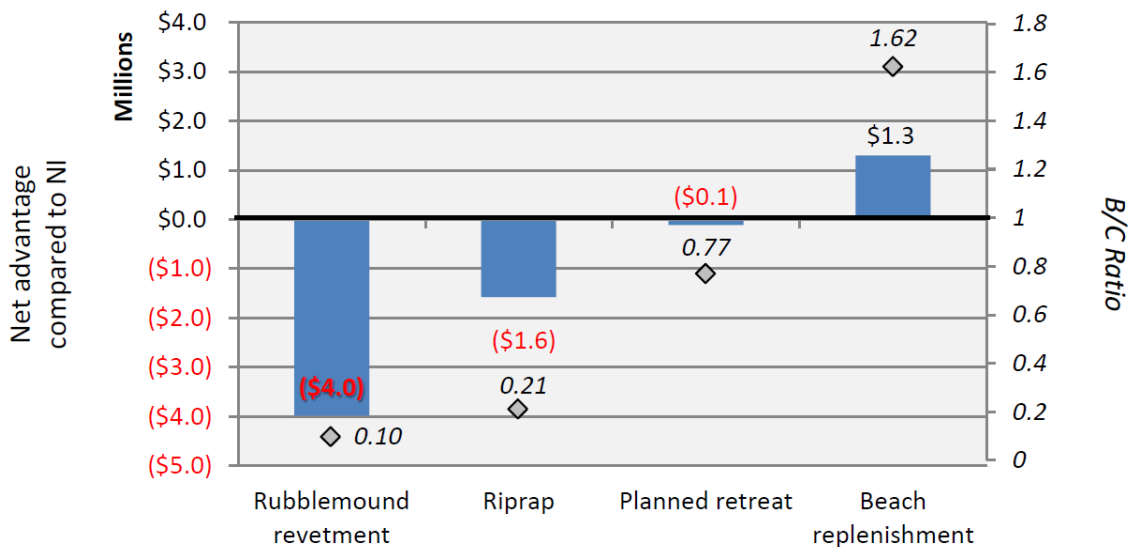


Figure 4.3 – Net Discounted Benefits Compared to Non-intervention and Benefit-cost Ratios in Anse du Nord

In light of these results, it is clear that the value of the built environment in Anse du Nord that will be at risk between 2015 and 2064 cannot alone justify the implementation of protection measures such as beach replenishment, rubblemound or riprap. These options must generate additional benefits, notably increased recreational use of the coast, to be considered more advantageous than inaction.

The sensitivity analyses show that the NPV of beach replenishment is robust. These analyses confirm that beach replenishment is the most economically beneficial option to fight coastal erosion in Anse du Nord, Percé.

4.7 CONCLUSION

The purpose of this cost-benefit analysis was essentially to compare various adaptation options for coastal areas in Percé in order to determine which would be the most economically beneficial. The CBA provides two economic indicators, net present value and benefit-cost ratio, that can help local, regional and national decision-makers choose the options best suited to the challenges that coastal communities will face over the next 50 years.

The results of the CBA clearly indicate that the most economically viable option for society as a whole is beach replenishment with pebbles in both Anse du Sud and Anse du Nord. The benefits of this option outweigh the costs in both cases, as this option favours the development of the coast and improves the tourism offering of Percé, in particular in Anse du Sud.

For the two other segments consisting of rocky cliffs (Côte Surprise and Mont-Joli Sud), planned retreat through the relocation of at-risk buildings is the only option that would preserve Percé's tourism infrastructures and heritage assets. Planned retreat is economically beneficial for Côte Surprise, where buildings are threatened with collapse in the short term.

This option should also be considered for the Mont-Joli Sud segment, where the historic Frederick-James Villa is in jeopardy. Although the CBA indicates that the options of planned retreat and non-intervention are almost equivalent in Mont-Joli Sud, the loss of the Frederick-James Villa would be a strike against Percé's heritage value as well as the beauty of the landscape, two aspects that are difficult to reliably assess in monetary terms.

In conclusion, this cost-benefit analysis has demonstrated that the most economically viable options are those that improve coastal use and the tourism offering while costing less to implement.



5. THE MARIA CASE STUDY

A linear town established on either side of Highway 132, Maria extends along the north shore of Chaleur Bay and is part of the MRC Avignon. The municipality's boundaries are Caps-de-Maria to the west and the mouth of Cascapédia River to the east. In 2014, the population in Maria was about 2,500.

As in many coastal communities, Maria is already experiencing serious climate change impacts, due to sea level rise, milder winters and loss of ice cover in Chaleur Bay, as well as changes in storm patterns. The eastward longshore drift and lowlands of unconsolidated sediment make Maria's coast highly vulnerable to erosion and flooding, as the impacts of the 2005 and 2010 storms showed.

5.1 STUDY AREA

Maria's study area was divided into four segments: Maria Centre-Ouest, Maria Centre-Est, Pointe-Verte Ouest and Pointe-Verte Est. These segments were defined based on the coast's physical characteristics and land use. Figure 5.1 identifies the boundaries of these segments.



Figure 5.1 – Location of the Study Area and the 4 Segments under Study in Maria

5.2 ADAPTATION OPTIONS

The technical adaptation options studied were drawn from a study realised for Ouranos by W.F. Baird & Associates Coastal Engineers (Baird). Taking into account the biophysical, geomorphologic and oceanographic parameters of Maria's coast, Baird has preliminary identified options that would protect the coast against 500-year events.

Table 5.1 lists the adaptation options studied in each segment.

Table 5.1 – Adaptation Options Considered in each Segment in Maria

Segment	Hard engineering structures	Soft engineering structures	Options without coastal structures
Maria Centre-Ouest	Sheet pile wall		Flood proofing and planned retreat
Maria Centre-Est	Concrete wall	Beach nourishment Beach nourishment with groynes	Flood proofing and planned retreat
Pointe-Verte Ouest	Concrete wall	Beach nourishment Beach nourishment with groynes	Flood proofing and planned retreat
Pointe-Verte Est	Concrete wall (sea side) Dykes (lee side)	Beach nourishment Beach nourishment with groynes	Flood proofing

The main conclusions for each segment are presented below.

5.3 MARIA CENTRE-OUEST

The first studied segment, Maria Centre-Ouest, extends from the point where Highway 132 leaves the coast to Parc du Vieux-Quai. It consists of a sandy beach terrace protected by a wall or rubblemound revetment along most of the segment. The probable erosion rate is -0.24 m/year and the 20-year flood levels are 3.95 m⁶, 4.16 m and 4.43 m respectively for 2015-2029, 2030-2054 and 2055-2064. Seventeen buildings in the segment will be partly or completely affected by erosion or flooding within 50 years, including a retirement home and the Coop-IGA store.

CBA results show expected damages of about \$4.5 million, at a discount rate of 4% over 50 years. Flooding is responsible for 95% of these damages. Among the adaptation

⁶ All flooding values are expressed in geodetic metres (m), i.e. the elevation in comparison with geodetic zero.

options examined, flood proofing combined with planned retreat is the least costly option with a -\$3.5 million NPV over 50 years, representing approximately a \$1 million net benefit over non-intervention.

5.4 MARIA CENTRE-EST

Between Parc du Vieux-Quai and Rue des Pluviers, Maria Centre-Est segment consists of beach terrace made up of sediment varying in size. The segment is characterized by a high rate of erosion (-0.83 m/year) and extreme flooding vulnerability, as its mean elevation is less than 3 metres. In comparison, 20-year flood levels of 2.81 m, 3.02 m and 3.29 m are expected respectively for 2015-2029, 2030-2054 and 2055-2064.

Since Parc du Vieux-Quai accounts for most of the segment, only nine residential buildings will be affected by erosion or flooding during the study period. As a whole, the cost of non-intervention is assessed to \$1.4 million over 50 years, discounted at 4%.

Given the few buildings at-risk, adaptation options based on soft or hard engineering structures, like beach nourishment and concrete seawall, are not economically justified within this segment. Flood proofing combined with planned retreat appears to be the favoured option versus non-intervention, as confirmed by various sensitivity analyses. However, net benefits of this option over non-intervention are relatively low, estimated at approximately \$25,000 over 50 years.

5.5 POINTE-VERTE OUEST

The Pointe-Verte Ouest segment is located between Rue des Pluviers and the area where the beach starts to widen (after the curve on Rue des Tournepierres). One-quarter of the segment is composed of a beach terrace and the other three-quarters, of a gravel spit.

In terms of flooding, expected 20-year flood levels are 2.81 m, 3.02 m and 3.29 m respectively for 2015-2029, 2030-2054 and 2055-2064. Coastline changes are quite significant for this segment, with a probable erosion rate of -0.76 m/year. The segment also has the highest level of artificialization along the shoreline.

Pointe-Verte Ouest has the highest number of buildings directly threatened by erosion or flooding over 50 years, i.e., 35 buildings. Without intervention, \$4.5 million of damages are expected over 50 years, discounted at 4%. Economically speaking, beach nourishment with groynes is the favoured option for this segment, with net benefits of \$1.2 million over non-intervention. However, an analysis of the optimal options in adjacent segments suggests that flood proofing combined with planned retreat should also be considered for consistency purposes. The net benefits of flood protection and planned retreat compared to non-intervention are about \$430,000.

5.6 POINTE-VERTE EST

The fourth segment, which begins at the boundary of the accretion zone and extends to the end of Pointe-Verte, is characterized by a spit dynamic. In fact, unlike the other segments, it is expected to gain 0.51 m/year of sediment in coming years thanks to the longshore drift. However, the maximum possible retreat for a single storm event is very high in this segment as it reaches -17.2 m/event. In terms of flooding, the 20-year flood levels are the same as for the two previous segments: 2.81 m, 3.02 m and 3.29 m respectively for 2015-2029, 2030-2054 and 2055-2064.

Anticipated damages from non-intervention over 50 years, discounted at 4%, total \$865,000. The economic analysis does not establish whether intervention is preferable over non-intervention. This is mainly due to the relatively low value of the at-risk built environment (nine buildings) and of the averted damages. In addition, the least costly adaptation option (flood proofing) would only protect two buildings from flood damage based on the intervention criterion selected for this study. This criterion is to flood-proof buildings when the 20-year flood level reaches the ground floor. Yet sensitivity analyses for water levels and for the rate of coastal erosion indicate that the increase in hazards would heavily favour intervention over non-intervention.

5.7 SYSTEMIC APPROACH

In Maria's study area, 70 residential and commercial buildings are vulnerable to erosion or flooding over the next 50 years. Inaction may lead to costs and damages estimated at \$11.3 million, using a discount rate of 4%. Three-quarters of this amount (\$8.8 million) is due to flood damage to buildings.

A scenario involving hard engineering structures for all segments, costing \$16.0 million, would lead to net costs of \$4.7 million over non-intervention, which makes this scenario non-viable economically. In contrast, favouring flood proofing and planned retreat for all segments would result in net discounted benefits of \$1.3 million over non-intervention.

Applying the flood proofing and planned retreat option to all segments is slightly less beneficial than implementing the optimal options for each individual segment. However, applying the flood proofing and planned retreat option throughout the study area would avert the potential negative impacts of beach nourishment with groynes on the Pointe-Verte Est segment. From a systemic perspective, the implementation of the same option over all four segments should be considered.

5.8 CONCLUSION

The findings of the CBA are reported in Figure 5.2. The results show that the most beneficial option for society as a whole is flood proofing and planned retreat for Maria Centre-Ouest, Maria Centre-Est and Pointe-Verte Est. For these segments, the flood proofing and planned retreat option entails the least costs as well as the lowest economic, social and environmental losses. However, for Maria Centre-Est and Pointe-Verte Est, the net benefits are under \$25,000 compared to non-intervention. The sensitivity analyses reveal that more severe coastal hazards than those projected would increase the benefits expected from implementing the flood proofing and planned retreat option.

Finally, from a systematic perspective, the option that comes in second for Pointe-Verte Ouest should be favoured over beach nourishment with groynes. This is an important aspect that decision makers will need to take into account when selecting the most advantageous adaptation options for the four studied segments in Maria.

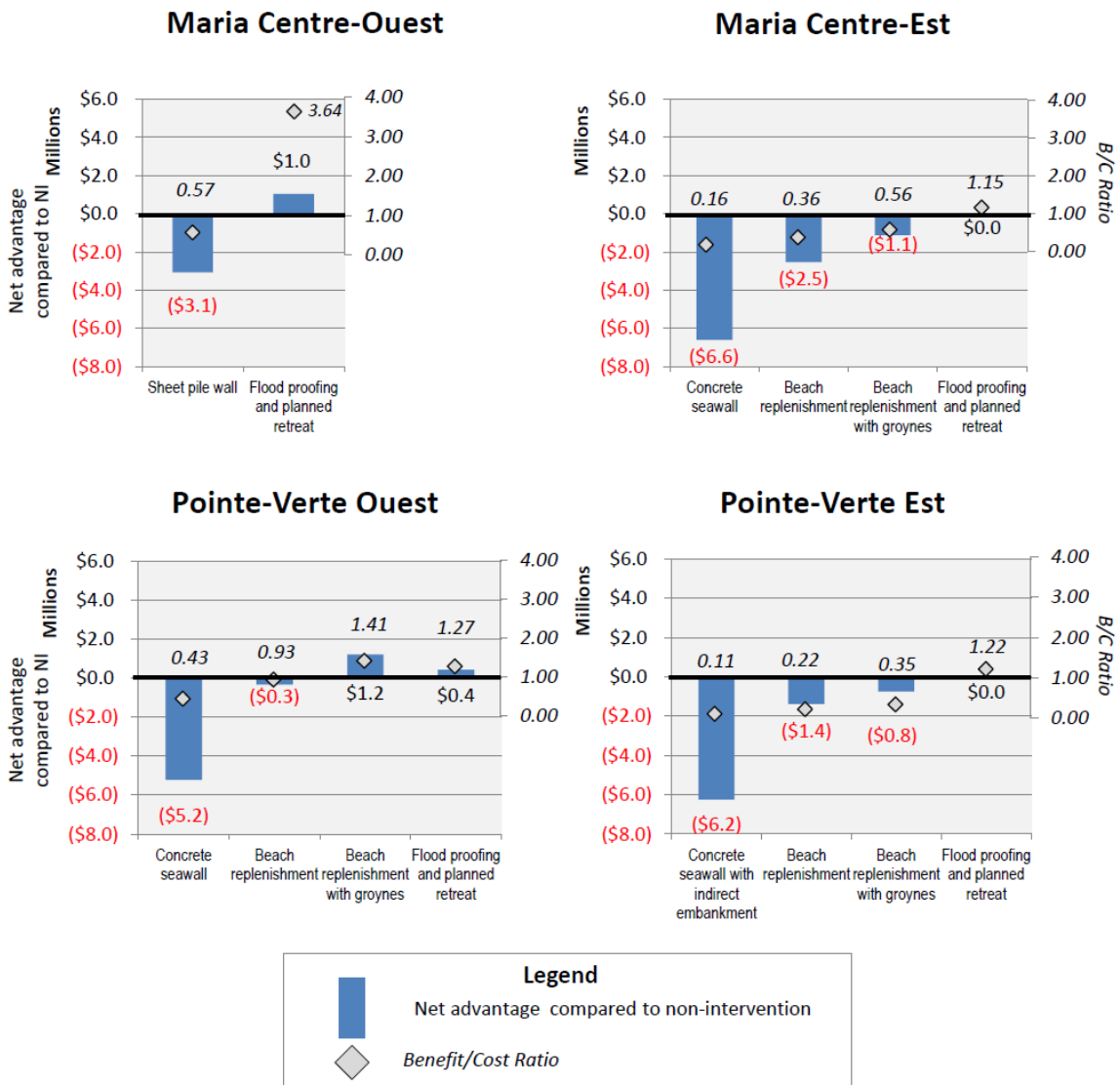


Figure 5.2 – Net Discounted Benefits Compared to Non-intervention and Benefit-cost Ratios for each segment in Maria



6. THE CARLETON-SUR-MER CASE STUDY

Located on Chaleur Bay, the town of Carleton-sur-Mer covers an area of 244 km² in the Avignon RCM. The town as we know it today is the product of a merger of two municipalities in 2000, St-Omer and Carleton, and is home to about 4,000 inhabitants. Carleton-sur-Mer is already experiencing serious climate change impacts, resulting in rising sea levels, milder winters and loss of ice cover in Chaleur Bay as well as changes in storm patterns. The coastal hazards of flooding and erosion are threatening seaside properties, buildings and infrastructure.

6.1 STUDY AREA

The study area covers the coast between the heart of St-Omer and the Caps de Maria, on a total length of 29.9 km. It was divided into 8 segments according to the physical characteristics of the coastline and land use. The segments were grouped in 3 sectors, namely Banc St-Omer, Berthelot-Éperlan and Carleton Est. The boundaries of these sectors are identified in Figure 6.1.



Figure 6.1 – Study Area and Location of the Three Sectors Examined in Carleton-sur-Mer

6.2 ADAPTATION OPTIONS

The adaptation options studied in Carleton-sur-Mer include hard engineering structures (rubblemounds, embankments, sea walls) and soft engineering structures (beach nourishment with or without groynes, beach nourishment with bioengineering, vegetated sand dunes), as well as an option without coastal structures combining flood proofing and planned retreat when assets are affected by erosion, flooding or both.

The adaptation options studied were drawn from a study realised for Ouranos by W.F. Baird & Associates Coastal Engineers (Baird). Taking into account the biophysical, geomorphological and oceanographic parameters of the Carleton-sur-Mer coast, Baird conducted a preliminary identification of structures that could protect the Carleton-sur-Mer coastline against 500-year storm events.

The main conclusions for each segment are presented below.

6.3 BANC ST-OMER SECTOR

The first sector studied is Banc St-Omer, which covers a distance of 6.5 km from Route Leblanc to Route Beaulieu. It comprises three segments with widely differing coastal issues: Banc St-Omer Ouest, Banc St-Omer Centre and Banc St-Omer Est. The boundaries of these segments are identified in Figure 6.2.



Figure 6.2 – Boundaries of the 3 Studied Segments in the Banc St-Omer Sector

The westernmost segment, Banc St-Omer Ouest, is dominated by sand spits and low cliffs of unconsolidated sediment. Close to 90% of the coast is natural. It is expected that, over the next 50 years, 58% of the coast will be eroding, while 42% will be stable or in a slight state of accretion. A total of 80% of the coast will also be subject to flooding. A number of homes have structures to prevent erosion or embankments against flooding.

The St-Omer sand bank protects a brackish marshland that is home to a diverse ecosystem of great ecological value. In fact, the St-Omer *barachois* or lagoon is an Environment Canada protected area. This area also attracts a large number of visitors who practice a wide range of recreational activities. The rear part of this segment, behind the lagoon, contains many homes and businesses in addition to the St-Omer Community Service Center (CLSC). Over the time horizon under study, a breach in the spit is expected to occur in 2017, increasing exposure of the buildings in the rear section to the risk of flooding (82 buildings over the study period) and erosion (1 building) hazards. This breach would imply the loss of the protected marshland and of visitor access to the spit.

If nothing is done, the CBA indicates anticipated damages estimated at close to \$5.9 million, discounted at 4% over 50 years. Almost 62% of these costs are due to the loss of use of the spit and 28% to flooding damages. Among the adaptation options studied, beach nourishment with sand is the most advantageous, generating close to \$2.7 million in benefits compared to non-intervention.

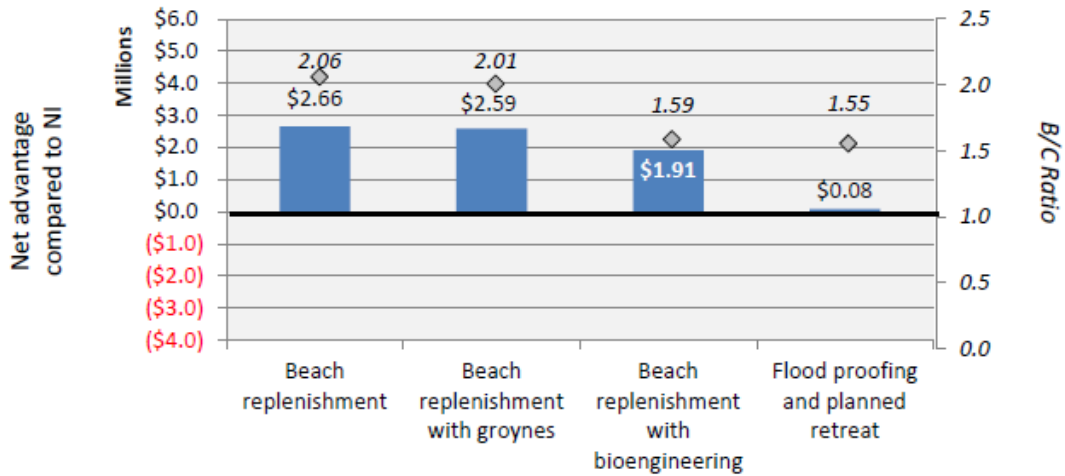
The Banc St-Omer Centre segment, which is about 0.5 km long, is comprised between Rue Caissy and Stewart River. It is almost entirely composed of beach terraces, almost half of which are eroding. While there are few buildings in this segment, the entire coast is subject to flooding episodes which could damage some buildings. In this segment, damages from coastal hazards are estimated to about \$724,000 over a 50 years period. Close to 88% of these damages are due to flooding. Flood proofing combined with planned retreat constitutes the most advantageous adaptation option for this segment, although its benefit compared to non-intervention is low, at just over \$20,000.

The last segment in this sector, Banc St-Omer Est, extends just under one kilometre from the Stewart River to Route Beaulieu. The coast here is quite low, and is mainly composed of beach terraces (58%) and low cliffs of unconsolidated sediment (29%). Even though homes in this segment are not exposed to short term erosion, the probable future erosion rate, in addition to the single-event retreat rate of the cliffs and beach terraces, will lead to damages over the medium and long term.

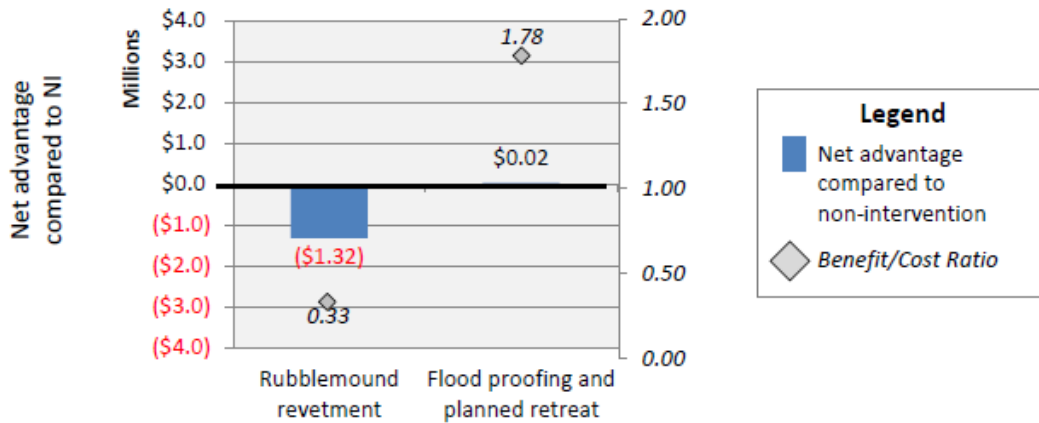
The CBA points to total damages for this segment of close to \$160,000, discounted at 4% over 50 years. Erosion, which will affect three buildings, is responsible for just over 90% of these damages. Planned retreat is the most beneficial adaptation option for this segment, although once again the difference between the NPV of this option and that of the non-intervention option is low.

Figure 6.3 presents the CBA results for all options studied in the Banc St-Omer sector.

Banc St-Omer Ouest



Banc St-Omer Centre



Banc St-Omer Est

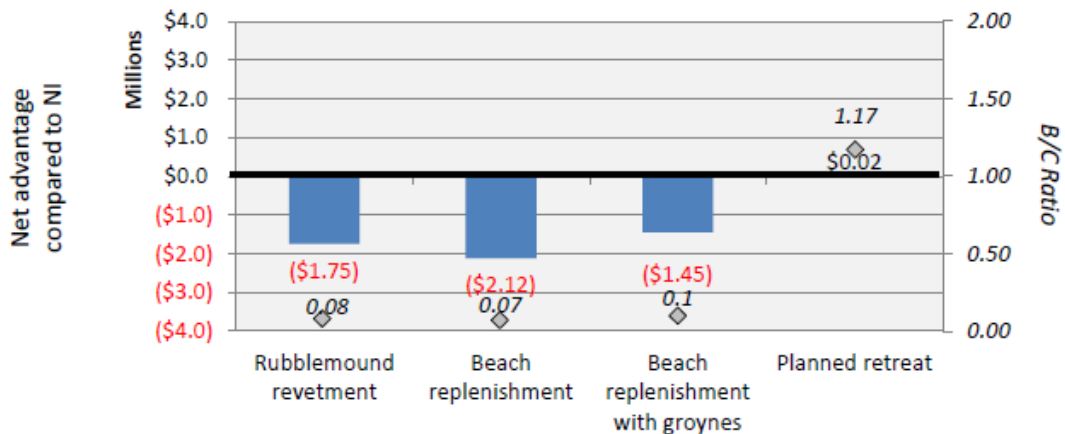


Figure 6.3 – Net Present Value Compared to Non-intervention and Benefit-cost Ratio of each Adaptation Option under Study per Segment in the St-Omer Sector

6.4 BERTHELOT-ÉPERLAN SECTOR

This sector extends for 1.4 km between Rue Berthelot and Rue Landry, all the way to the point where the latter reaches the coast. The rail corridor was excluded from the study, as any intervention to protect this segment should be part of efforts to rehabilitate the entire railway. This sector includes two segments, Rue Berthelot and Ruisseau de l'Éperlan, whose boundaries are identified in Figure 6.4.



Figure 6.4 – Boundaries of the 2 Segments Studied in the Berthelot-Éperlan Sector

The Rue Berthelot segment is bounded by Route 132 and the railway. Composed of low unconsolidated sediment cliffs, it is a residential area protected by a several metres high rubblemound in good condition. This rubblemound has slowed down coastal erosion, but at the cost of beach loss. Storm waves strike the protective structures with great force, which could eventually cause their collapse. Over the next 50 years, erosion threatens 7 of the segment's 11 homes, but no building is vulnerable to flooding.

According to the CBA results, damages in this segment would amount to close to \$200,000, 14% of which would be linked to the physical loss of land while 54% would be due to the demolition of 3 homes. In this segment, the non-intervention option requires

protecting the access route from Highway 132 to Rue Berthelot for the street's residents. Non-intervention is the least costly option, as planned retreat costs exceeds those of losing the homes exposed to erosion over the next 50 years.

The Ruisseau de l'Éperlan segment extends over almost 1 km between Chemin de la Mer and Rue Landry. The stream's delta lies in the centre of the segment, bordered by a beach terrace and flanked on either side by unconsolidated sediment cliffs. With a retreat rate between -0.24 and -0.35 m per year, this segment is at risk of erosion and two-thirds of its coast is artificialized. A number of cottages and trailers have been set up along the top of the cliff to the west of the stream, while to the east there are primary residences exposed to erosion. For this segment, the CBA indicates that discounted damages over the next 50 years would total approximately \$300,000. As is the case for the Rue Berthelot segment, all adaptation options studied for the Ruisseau de l'Éperlan segment are more costly than non-intervention.

Figure 6.5 presents the CBA results for the adaptation options studied in the Rue Berthelot and Ruisseau de l'Éperlan segments.

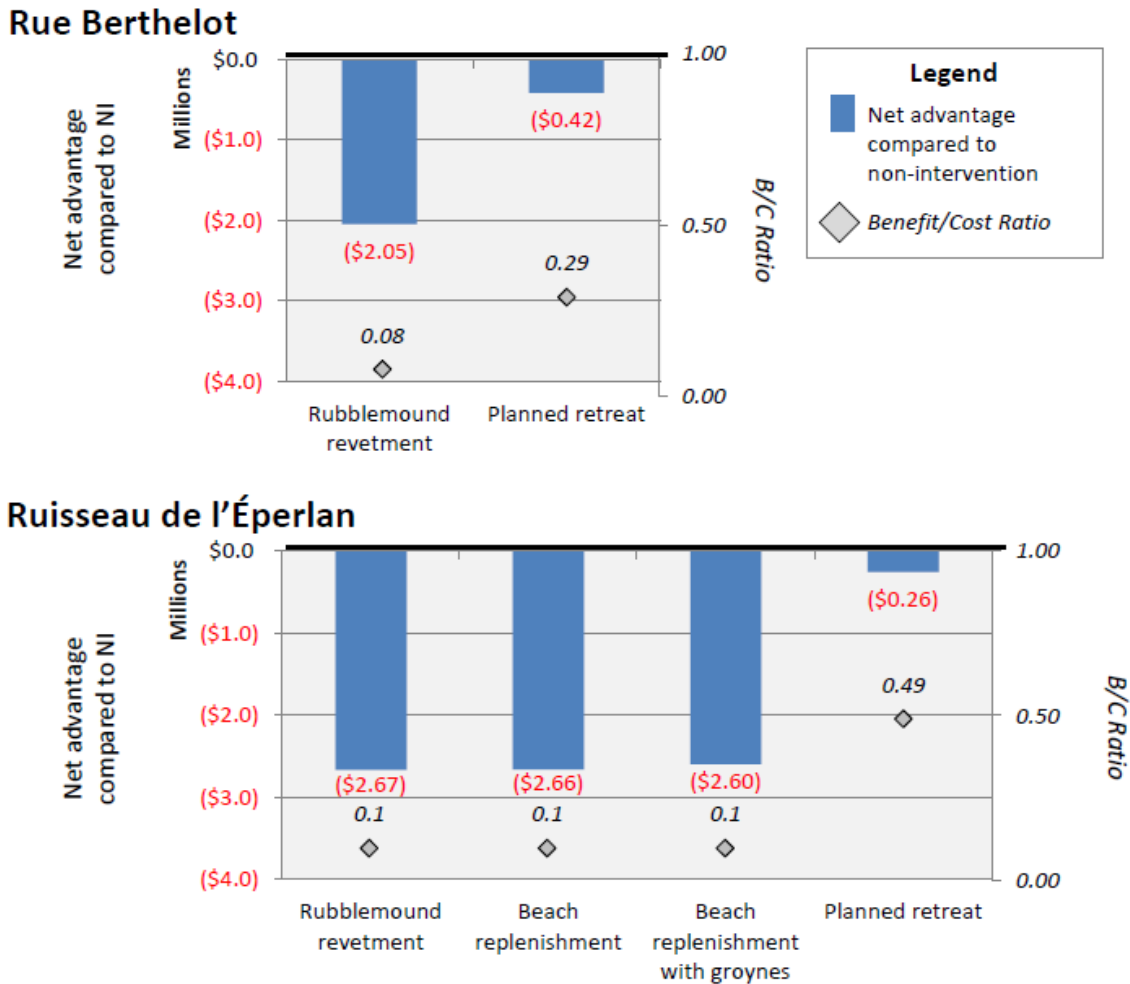


Figure 6.5 – Net Present Value Compared to Non-intervention and Benefit-cost Ratio of each Adaptation Option under Study per Segment in the Berthelot-Éperlan Sector

6.5 CARLETON EST SECTOR

The Carleton Est sector covers a stretch of more than 10.6 km in the heart of the city of Carleton-sur-Mer, and contains the most important services and infrastructures. This sector includes three segments with very different coastal dynamics: Plage municipale, Pédoncule and Caps de Maria. Figure 6.6 identifies the boundaries of each segment.



Figure 6.6 – Boundaries of the 3 Segments Studied in the Carleton Est Sector

To the west, the Plage municipale segment runs close to a kilometre from Rue de la Gare to the Carleton wharf. Carleton's municipal beach is located on a spit and is historically under accretion, nourished by sediments from Ruisseau de l'Éperlan and the nearby unconsolidated sedimentary cliffs. However, the last 200 m of beach before the wharf are eroding (-0.21 m/year) and the section before the wharf is artificialized.

This segment experiences problems with flooding caused by direct surges along the waterfront and breaking waves to the east of the wharf. Over a period of 50 years, some thirty buildings and infrastructures in the western part of the segment will be affected by flooding events. The road leading to the Carleton wharf is also subject to flooding, but the episodes are not long enough to lead to economic losses by compromising the activities that depend on wharf access.

According to the CBA results, the cost of inaction on the time horizon under consideration would amount to \$6.1 million, 74% of which would be damages associated with flooding. Among the adaptation options studied for this segment, flood proofing of

buildings proves to be the most advantageous, producing a net benefit of \$1.85 million compared to non-intervention.

Located on the municipal campground sand spit that shelters the Carleton lagoon, the Pédoncule segment extends for 1 km from the start of the neck of the spit (thinnest section at the landward end of the spit) to the curve in the campground road. To protect it from the erosion and flooding hazards during storms, two-third of the segment has been artificialized, mainly by rubblemound and wooden sea walls. Despite the sediment contribution from the capes of Maria, the coastal dynamic in this location does not allow accumulation.

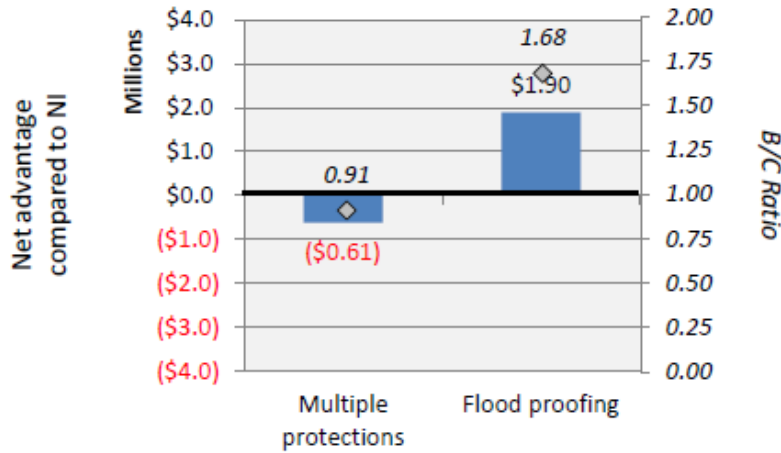
If nothing is done, erosion could cut through the neck of the spit by around 2040, preventing road access to the campground and resulting in the loss of camping-related revenues. The results of the CBA show that the damages associated with inaction, discounted at 4%, would amount to \$3.25 million over 50 years in this segment. Among the adaptation options studied, beach nourishment with groynes is the most advantageous option, providing a net benefit of just over \$1.24 million.

The Caps de Maria segment stretches on 5.4 km from Avenue du Phare to Auberge des Caps. It is essentially composed of unconsolidated sediment cliffs some 20 to 30 m in height, which are eroding at a rate varying between -0.28 m and -0.69 m per year. The resulting sediment contributes to replenishing the Carleton lagoon sand spit. This segment is therefore essential for slowing down the creation of a breach in the neck of the spit in the Pédoncule segment.

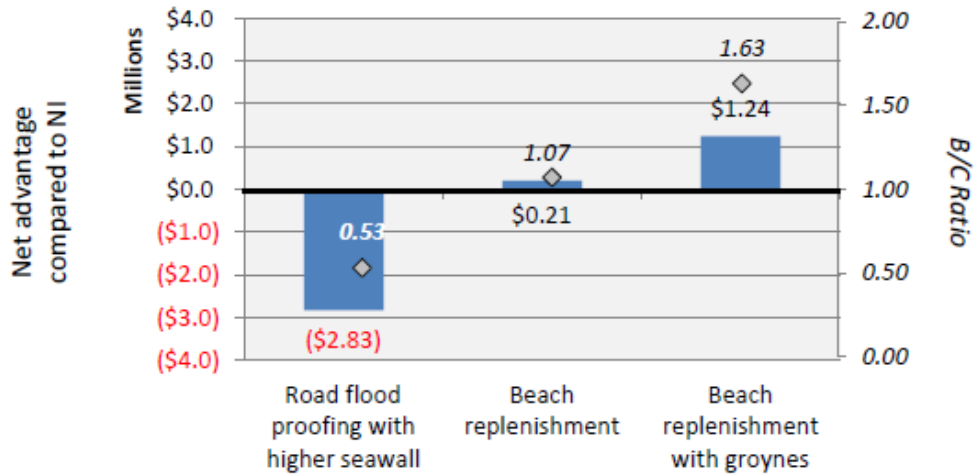
Over the time horizon under study, erosion is expected to lead to the loss of a strip of land 14 to 35 metres wide, which will affect some thirty homes located at the top of the cliffs. Despite these potential losses, the CBA results indicate that non-intervention constitutes the least costly option for this segment with discounted costs evaluated at around \$1.54 million. Planned retreat in this location would involve additional costs of \$1.37 million.

Figure 6.7 presents the results of the CBA for all adaptation options studied in the Carleton Est sector.

Plage municipale



Pédoncule



Caps de Maria Ouest

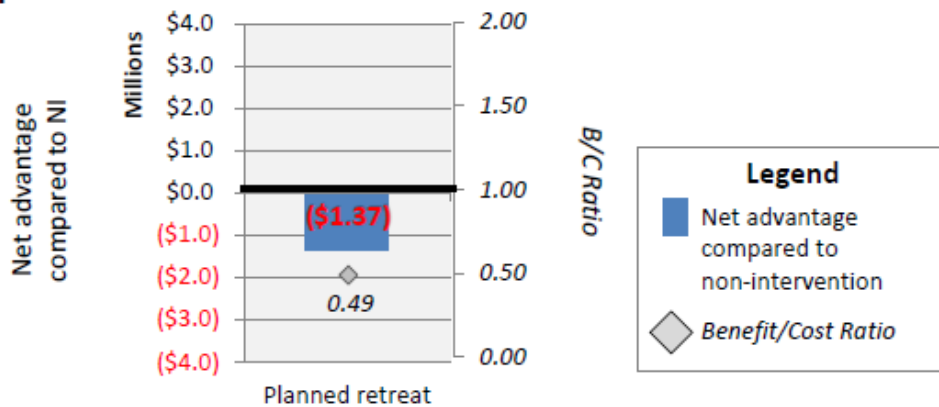


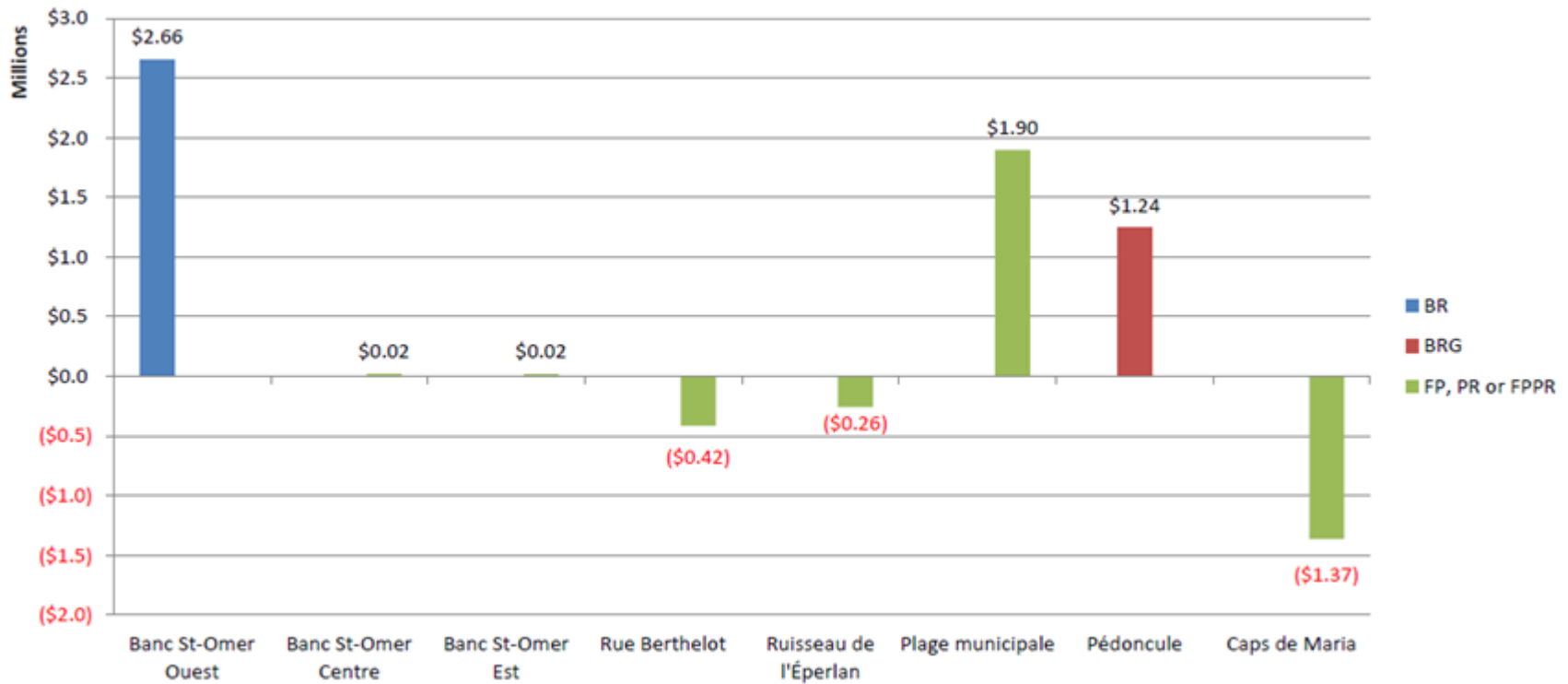
Figure 6.7 – Net Present Value Compared to Non-intervention and Benefit-cost Ratio of each Adaptation Option under Study per Segment in the Carleton Est Sector

6.6 CONCLUSION

The purpose of this cost-benefit analysis is to help decision makers to select the most beneficial adaptation options for avoiding damages to the Carleton-sur-Mer coast, by comparing the economic costs and benefits over a time horizon of 50 years.

Figure 6.8 shows the net present value of the most advantageous option in comparison with non-intervention for each of the 8 segments under study. For 3 segments, Rue Berthelot, Ruisseau de l'Éperlan and Caps de Maria, the non-intervention option constitutes the most economically viable option. For the Banc St-Omer Ouest, Plage municipale and Pédoncule segments, the implementation of different options, namely beach nourishment, flood proofing of buildings and beach nourishment with groynes respectively, is clearly preferable to non-intervention. For the Banc St-Omer Centre and Banc St-Omer Est segments, the net benefits of the most advantageous option (flood proofing and/or planned retreat) over non-intervention are so low that no clear conclusion can be drawn as to the option to favour economically.

The CBA results are primarily influenced by the extent of expected damages, the value of the land and properties in need of protection, the use of the coast, and by the costs of the proposed adaptation options over the time horizon. Along the Carleton-sur-Mer coastline, the implementation cost of hard engineering structures is appreciably higher than the value of the expected damages, rendering such options unjustified from an economic point of view. For the Banc St-Omer Ouest and Pédoncule segments, where the use value of the coast is high, soft engineering structures that preserve this value are the most beneficial. In cases where value of the land and buildings affected by coastal hazards is relatively high, as is the case for the Plage municipale segment and, to a lesser extent, the Banc St-Omer Centre and Banc St-Omer Est segments, planned retreat combined to flood proofing appears to be more advantageous than inaction for society as a whole.



Legend: BR= Beach replenishment, BRG= Beach replenishment with groynes, FP= Flood proofing, PR= Planned retreat, FPPR= FP+RP

Figure 6.8 – Net Present Value of the Most Advantageous Option Compared to Non-intervention in Carleton-sur-Mer



7. THE ÎLES-DE-LA-MADELEINE CASE STUDY

In the heart of the Gulf of St. Lawrence, the archipelago of Îles-de-la-Madeleine is located 105 km from Prince Edward Island, 95 km from Cape Breton, and 215 km from the Gaspé Peninsula. The municipality of Îles-de-la-Madeleine has already been considerably affected by coastal hazards, an impact that will only worsen with climate change. Changes in hydroclimatic parameters, particularly the expected 50 cm sea-level rise in 2055 over the 1986–2005 period, and the reduction in ice cover will accelerate the erosion and flooding to which the archipelago is already subjected. A number of seaside infrastructures are threatened, including residential and commercial buildings, as well as major tourism installations and sites that are vital to the municipality's economy and tourism industry.

7.1 STUDY AREA

The Îles-de-la-Madeleine study area was divided into 3 sectors: Cap-aux-Meules, La Grave and Grande-Entrée. These sectors were initially divided into 20 coastal segments according to the physical characteristics of the coastline and land use. A more detailed analysis led to the selection of 6 segments in the Caps-aux-Meules sector, one in the La Grave sector and one in the Grande-Entrée sector for a total of 8 segments. Figure 7.1 presents the three sectors under study in Îles-de-la-Madeleine.

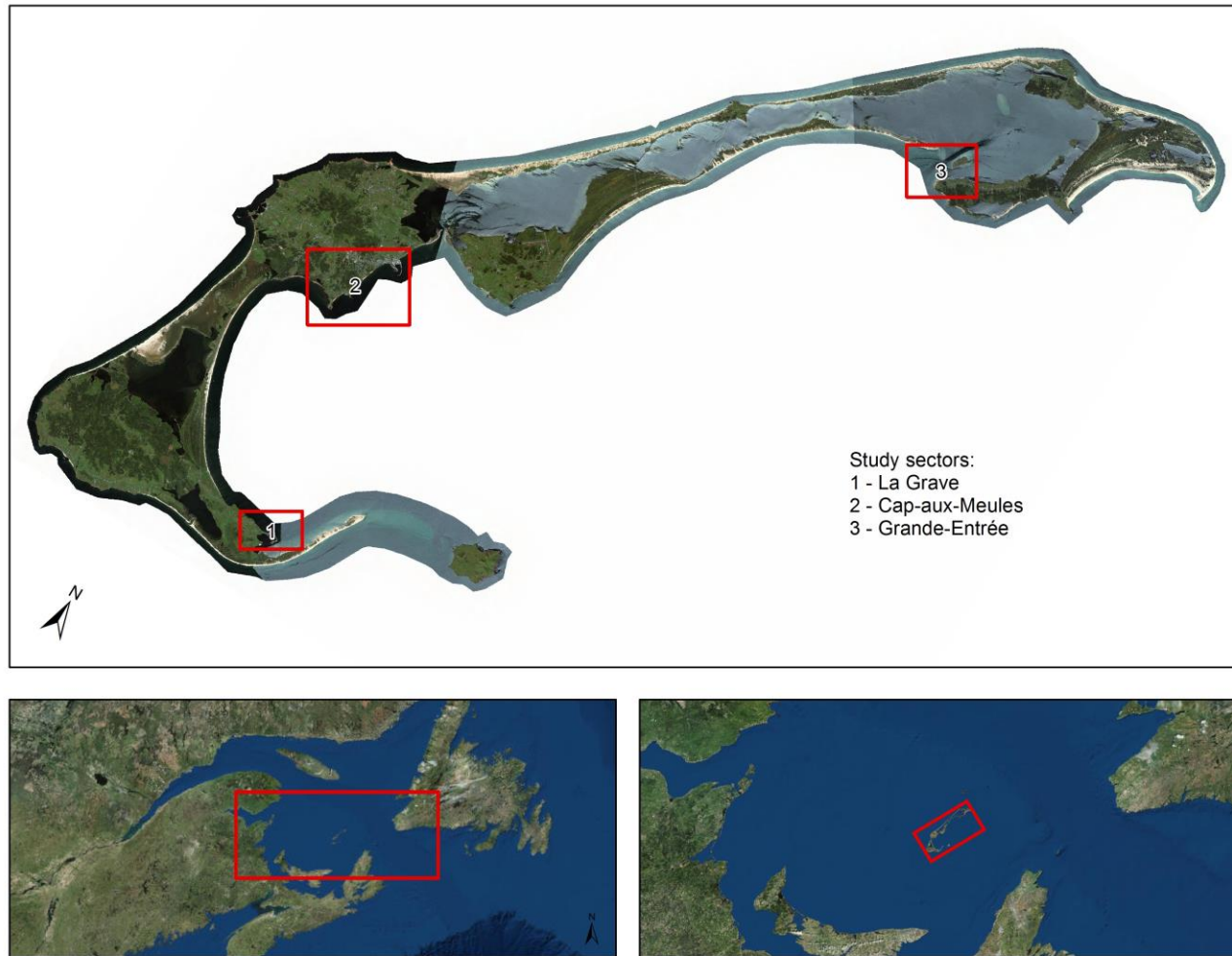


Figure 7.1 – Study Area and Location of the Three Sectors under Study in Îles-de-la-Madeleine

7.2 ADAPTATION OPTIONS

The adaptation options studied include hard (riprap, rubblemound) and soft engineering structures (beach nourishment with or without groynes, beach nourishment using gravel, beach nourishment with toe blocks), as well as an option without coastal structures combining flood proofing and planned retreat when assets are affected by erosion, flooding or both. The adaptation options considered in each of the 8 segments under study are presented in Table 7.1.

Table 7.1 – Adaptation Options Considered in each Segment in Îles-de-la-Madeleine

Sector	Segment	Hard engineering structure	Soft engineering structure	Options without coastal structures
Cap-aux-Meules	Camping Gros-Cap	Riprap Rubblemound		Planned retreat
	Gros-Cap Est	Riprap Rubblemound	Beach nourishment with toe blocks	Planned retreat
	Échouerie Ouest	Riprap Rubblemound		Planned retreat
	Route municipale	Riprap Rubblemound		Planned retreat
	Plage municipale	Riprap Rubblemound	Beach nourishment with toe blocks	Planned retreat
	Centre-ville	Riprap Rubblemound		Planned retreat
La Grave		Riprap Rubblemound	Beach nourishment with gravel	Flood proofing and planned retreat
Grande-Entrée		Riprap Rubblemound	Beach nourishment with groynes	Flood proofing and planned retreat

The technical solutions studied, in particular the engineering structures, were drawn from a conceptual study conducted by Roche (Roche, 2011) and an additional study which assessed the technical feasibility of certain adaptation options in La Grave, conducted by Consultants Ropars (Ropars, 2016). These conceptual studies provide only a

preliminary assessment of the possible options. The design of the structures takes into account the hydrodynamic conditions, erosion, sedimentation and geotechnical constraints associated with the segments under study. The adaptation options were designed to avoid all problems of erosion and flooding over the next 50 years.

The main conclusions for each of the three Îles-de-la-Madeleine sectors are presented below.

7.3 CAP-AUX-MEULES SECTOR

The Cap-aux-Meules sector is made up of 14 segments, 6 of which were selected for economic analysis. The segments that underwent cost-benefit analysis are presented in Figure 7.2. They cover more than 6 km of coastline, alternating between beach terraces and sandstone cliffs. The segments studied contain a variety of assets of great importance to the regional economy and to tourism in Îles-de-la-Madeleine, including the Gros-Cap campground, a municipal beach, a multipurpose trail, tourist accommodations and a major industrial building.

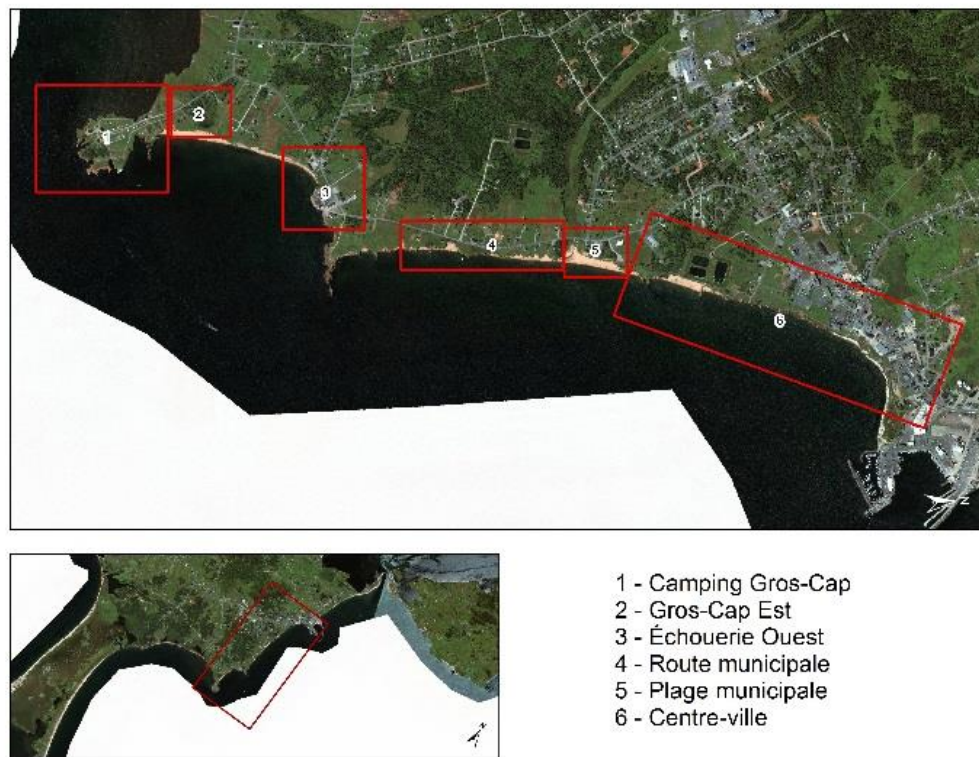


Figure 7.2 – Cap-aux-Meules Sector and the 6 Segments Selected for the CBA

Table 7.2 provides a summary of the CBA results for each of the segments in the Cap-aux-Meules sector. A number of observations can be made based on these findings. First of all, in 5 of the 6 segments under study, it is preferable to intervene rather than do nothing. The only exception is the Route municipale segment, which can be explained by the low value of the assets at risk in this sector. Second, in segments where there are significant economic or tourism resources at stake, hard engineering structures such as riprap are justifiable to preserve the assets close to the coast and the economic activities that depend on them. This is the case in the Camping du Gros-Cap, Échouerie Ouest and Centre-ville segments.

Table 7.2 – Most Advantageous Adaptation Option, Net Benefit Compared to Non-intervention and Benefit-cost Ratio for each Segment in Cap-aux-Meules

Segment	Most advantageous adaptation option	Net benefit compared to non-intervention	Benefit-cost ratio
Camping du Gros-Cap	Riprap	\$6,287,928	4.54
Gros-Cap Est	Planned retreat	\$17,585	1.29
Échouerie Ouest	Riprap	\$4,227,590	2.54
Route municipale	Non-intervention	-	NA
Plage municipale	Planned retreat	\$147,561	1.72
Centre-Ville	Riprap	\$591,227	1.07

Finally, planned retreat is the option of choice in the Plage municipale and Gros-Cap Est segments, where there are few built assets and where any coastal intervention would restrict coastal use.

The net benefits compared to non-intervention and benefit-cost ratios make it possible to put into perspective the viability of the adaptation options favoured by the CBA. Some adaptation options generate net benefits of several million dollars compared to non-intervention (Camping du Gros-Cap and Échouerie Ouest). These are also the adaptation options with the highest benefit-cost ratios. In other words, these measures both maximize the total benefits generated by the intervention and the benefits for every dollar invested.

Segments where planned retreat is the most advantageous option have much lower net benefits, while their benefit-cost ratios indicate that the option is a viable one. Planned retreat generates low benefits, but costs little to implement.

Most of the sensitivity analyses indicate that the most beneficial adaptation options in the 6 segments are robust to changes in the CBA basic assumptions. The only exception is the Centre-ville segment, where the sensitivity analyses favour either riprap or non-intervention, depending on the assumptions. This result must be put into perspective given that the effectiveness of riprap has not been confirmed by a specific engineering study for this segment. The height of the cliffs makes it likely that there are additional erosion processes at work, such as wind and freeze-thaw erosion. It is possible that riprap protection at the base of the cliff would not be able to slow all of the active erosion processes.

7.4 LA GRAVE

The La Grave sector is 6.5 km long and is made up of five segments with widely differing coastal characteristics and vulnerability levels. Following a preliminary analysis of the five segments, only the La Grave historic site was selected for the purpose of the economic analysis. The La Grave segment comprises a 440 m long tombolo joining two rocky islets. It is home to the historic, heritage and cultural heart of La Grave.

The CBA evaluated the discounted value of the anticipated impacts of non-intervention in this segment at more than \$40 million over 50 years, primarily due to losses in tourism and a decrease in the use value of the site. All of the adaptation options considered, with the exception of flood proofing and planned retreat, are able to fully preserve most of the La Grave segment.

As presented in Figure 7.3, the most economically viable adaptation option is beach nourishment using gravel due to relatively low implementation costs and enhanced use value of the coast. Sensitivity analyses confirmed the robustness of this result to changes in key variables (discount rate, extreme water levels and economic impacts).

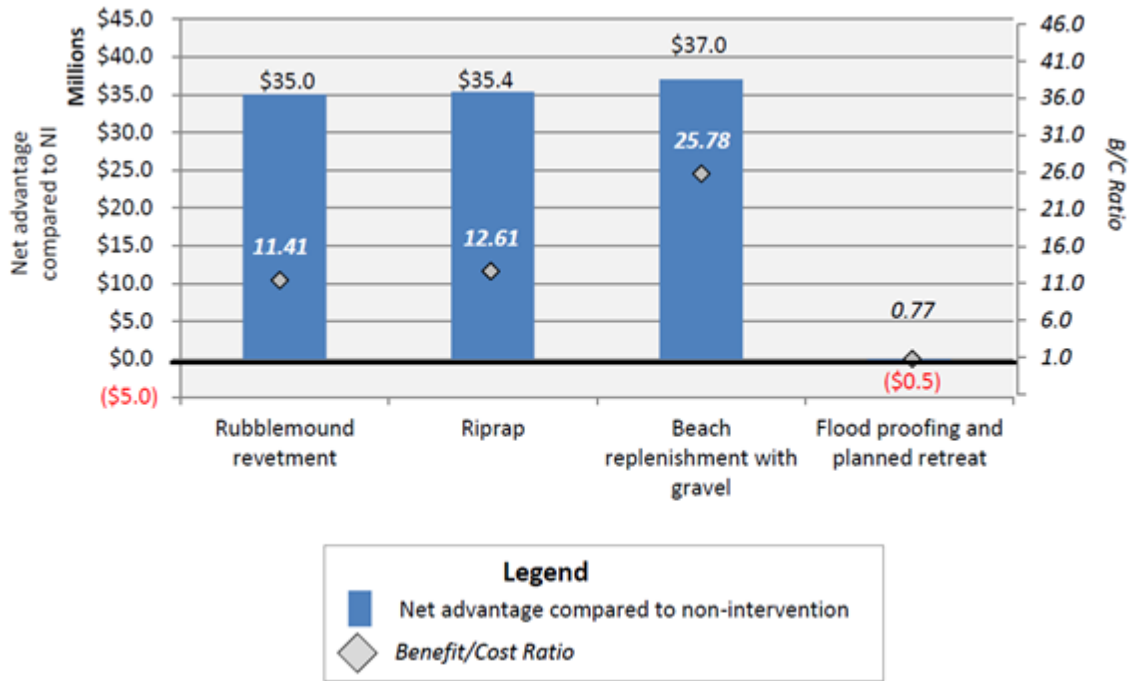


Figure 7.3 – Net Discounted Benefits Compared to Non-intervention and Benefit-cost Ratio of each Adaptation Option in La Grave

7.5 GRANDE-ENTRÉE

The Pointe de Grande-Entrée segment is a low-lying area that has been largely artificialized by the harbour facilities, which are home to the largest fishing fleet in Îles-de-la-Madeleine. The non-artificialized section is composed of a beach terrace that has been retreating rapidly since the mid-2000s.

Over the next fifty years, erosion will encroach a significant portion of Pointe de Grande-Entrée, but this will not affect the major infrastructures within the segment, namely the harbour facilities and the seafood processing plant. With regard to flooding, episodes of extreme water levels will damage some residential and commercial buildings in the segment.

Despite these anticipated impacts, the CBA showed non-intervention to be the most beneficial option for this segment economically. The engineering options considered are too expensive in comparison with the damages they could avoid, even when using minimal construction costs, while the option of flood proofing and planned retreat is not

economically viable. As a result, given the current conditions in the Pointe de Grande-Entrée segment and the predicted evolution of coastal hazards over the next fifty years, it appears more economically advantageous not to take action.

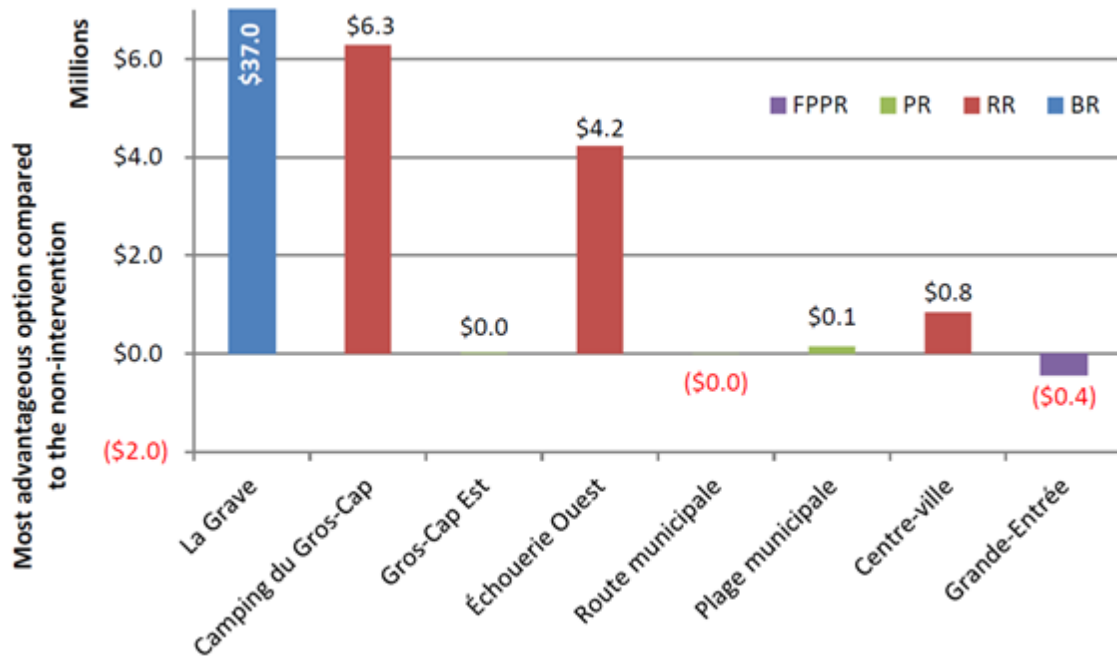
7.6 CONCLUSION

The purpose of this cost-benefit analysis was to help decision makers to select the most beneficial adaptation options for avoiding damage to the Îles-de-la-Madeleine coast caused by coastal hazards, by comparing the economic costs and benefits of the different options over a time horizon of 50 years.

Figure 7.4 shows the net present value of the most advantageous option in comparison with the non-intervention option for each of the 8 segments under study. For 2 segments, Route municipale and Pointe de Grande-Entrée, the non-intervention constitutes the most economically viable solution. For the La Grave, Camping du Gros-Cap, Échouerie Ouest, Centre-ville and Plage municipale segments, the implementation of different options is clearly preferable to non-intervention. In the Gros Cap Est segment, the net benefits of the most advantageous option (planned retreat) over non-intervention are so low that no clear conclusion can be drawn as to the more economically viable option.

Of the coastal segments in Îles-de-la-Madeleine that are in need of protection, some are home to major economic assets or widely used tourist attractions that are vulnerable to erosion. Given the value of anticipated losses and the type of coast on which these infrastructures are located (low rocky cliffs), hard engineering structures such as riprap are economically justified. Other segments, situated on low-lying coasts where coastal use has a significant value for both tourists and residents alike, the preferred adaptation options favour maintaining a natural coast through soft engineering structures or the planned retreat of assets. Such is the case in the Plage municipale and La Grave segments.

Finally, in segments where the anticipated impacts are low, such as Gros-Cap Est and Route municipale, the adaptation options considered are only slightly beneficial or are not economically justified.



Legend: FPPR: Flood proofing and planned retreat; PR: Planned retreat; RR: Riprap; BR: Beach replenishment

Figure 7.4 – Net Present Value of the Most Advantageous Option Compared to Non-intervention in Îles-de-la-Madeleine



8. THE RIVIÈRE-OUELLE CASE STUDY

This case study covers an area located in the municipalities of Rivière-Ouelle and La Pocatière, which are both on the south shore of the St. Lawrence River in the MRC de Kamouraska. This area is known for its rich clay soils. Farmland is protected by a 4.2 km long agricultural dike built out of soil in the 1930s to drain the land and protect it from flooding to allow for agricultural use. A marsh in front of the agriculture dike protects the structure from erosion and flooding hazards, as it absorbs the energy of storm waves. The Rivière-Ouelle⁷ dike is considered vulnerable as it might be highly affected by erosion in the coming years.

8.1 STUDY AREA

The study area comprises 370 hectares between Highway 20, Route 132, the Saint-Jean River and the Ouelle River, as indicated in Figure 8.1. The agricultural dike protecting farmland has an average height of 3.9 metres.

⁷ Although the study area includes land located in two municipalities, it is the Rivière-Ouelle agricultural dike that is threatened during the time period of the study. That is why this case study is entitled *Cost-Benefit Analysis of Coastal Adaptation Options in Rivière-Ouelle*.



Figure 8.1 – Location of the Study Area in the Rivière-Ouelle Case Study

8.2 ADAPTATION OPTIONS

In Rivière-Ouelle, four adaptation options were evaluated in order to meet one of the following objectives: 1) to avoid any breach in the agricultural dike, thereby protecting most of the farmland at risk, or 2) to allow the marsh to regenerate, ensuring long-term protection of the agricultural dike. Given rising sea levels, the four options considered all

include raising the agricultural dike from an average height of 3.9 geodetic metres to around 5 geodetic metres.

The first option considered is to protect the agricultural dike by building a T-shaped rock groyne in front of the section of the agricultural dike most vulnerable to erosion of the marsh. The second measure consists of armouring the agricultural dike with riprap to make it able to withstand erosion and avoid the formation of breaches. The third option is based on the partial retreat of the most vulnerable section of the agricultural dike (loss of about 14 hectares of farmland), to allow the marsh to continue to provide natural protection against erosion. Finally, the fourth option, salt marsh restoration, involves moving the agricultural dike back to Rang de l'Éventail, thereby allowing the marsh to regenerate over a potential area of 200 hectares.

The technical solutions studied, in particular the engineering structures, were drawn from various technical studies conducted in recent years in the territory of the MRC de Kamouraska on the rehabilitation and/or maintenance of the region's agricultural dikes. They take into account the hydrodynamic conditions, erosion, sedimentation and geotechnical constraints associated with the study area. The adaptation options studied in this analysis were designed to avoid all problems of erosion and flooding over the next 50 years.

8.3 ISSUE

The main issue of concern within the study area is the disappearance of the marsh, which could lead to breaches in the agricultural dike and recurrent flooding of the farmland. The farmland currently floods only on rare occasions during major storms such as the one that occurred in December 2010 when the water level exceeds the dyke elevation.

Normally, the presence of the salt marsh protects the agricultural dike. However, with the marsh retreating at a projected rate of -1.93 metres per year at its most critical point, the agricultural dike will be exposed to erosion in 2035. As the dike was not designed to withstand the force of waves, it is expected that breaches will form and salt water will flood the lowest-lying sections of farmland.

Over a time horizon of 50 years, if nothing is done, more than 200 hectares of agricultural land could be lost in the area under study. However, the flooded farmland would favour the regeneration of the marsh, which could gradually increase in area. Indeed, the lost farmland could partially revert to a natural salt marsh providing ecological services including a habitat for biodiversity.

The potential impacts of non-intervention are estimated at \$619,571 over 50 years at a discount rate of 4%. Most of the anticipated damages stem from the loss of cultivable land, which is evaluated at \$10,000 per hectare in the region.

8.4 CBA RESULTS

The results of the CBA show that partial retreat of the agricultural dike is an economically beneficial option compared to non-intervention over a period of 50 years. Unlike the other adaptation options, partial retreat has a low construction cost and favours the restoration of the salt marsh over an area of 14 hectares, enabling it to continue to protect the agricultural dike from erosion. Over the study period, partial retreat of the agricultural dike generates net present benefits of \$189,308 compared to non-intervention (see Figure 8.2). Every dollar spent on this option will generate benefits of \$1.37 for society as a whole.

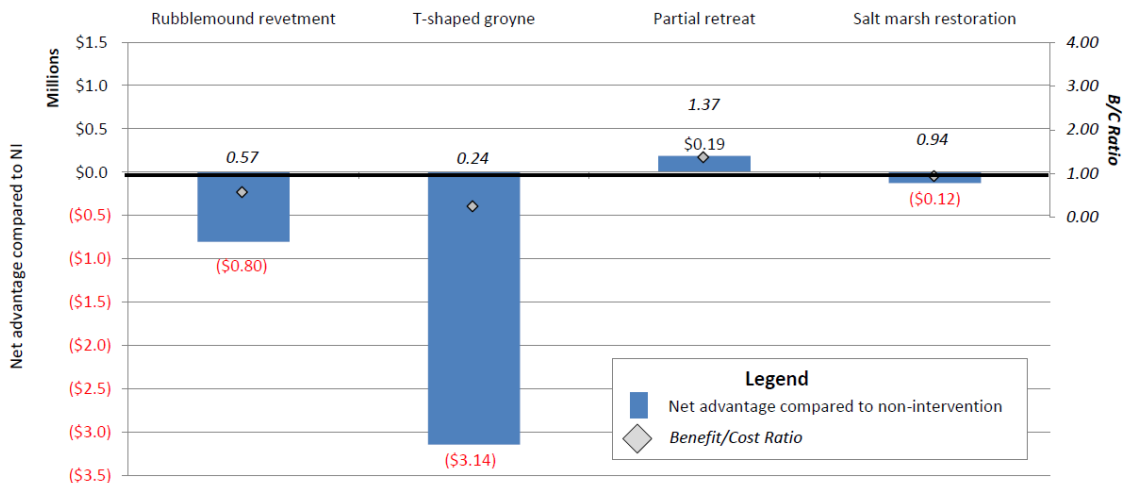


Figure 8.2 – Net Present Value Compared to Non-intervention and Benefit-cost Ratio of each Adaptation Options in Rivière-Ouelle

Sensitivity analyses indicate that the CBA results are affected by the value of the ecological services provided by the marsh and by the rate at which the marsh could regenerate and provide these ecological services. When the value of the ecological services increases or the marsh regenerates more quickly, salt marsh restoration becomes the most economically viable option. Unfortunately, the environmental benefits are difficult to assess in monetary terms, as there are no observable market transactions for ecological services. Moreover, the conditions that ensure marshland regeneration are still relatively unknown.

On the whole, the sensitivity analyses point to partial retreat combined with raising the agricultural dike as the most beneficial option. This solution restores the natural protection of the agricultural dike provided by the salt marsh, avoiding the need to armour the agricultural dike or protect it with a T-groyne, both of which are costly options in comparison with the expected damage over the next 50 years.



9. INTEGRATED RESULTS

Together, the five case studies summarized above examined 25 coastal segments representative of coastal issues in Quebec. The sections that follow provide an integrated analysis of these 25 cost-benefit analyses and extract the main findings.

9.1 NON-INTERVENTION COSTS

Two findings can be formulated concerning the costs for non-intervention. The first regards the breakdown of costs between flooding and erosion, while the second regards the wide range of costs based on at-risk assets and their associated economic activities.

Breakdown of costs between erosion and flooding

Although erosion is a more frequent issue than flooding, flooding is a major component of the damages associated with non-intervention. In the segments retained for analysis, 56% of segments are facing erosion only, 4% are facing flooding only, and 40% are facing both. However, of the roughly \$28M in estimated damages due to erosion and flooding, close to \$20M are attributable to damages from flooding (71%), whereas only \$8M are a direct consequence of erosion.

This finding is of course associated with the methodologies used to calculate the costs for both hazards. However, it especially reflects the recurrent aspect of flood damages as opposed to erosion damages. Over a 50-year study period, a building may suffer total flood damages greater than the building's value, while erosion will lead to total loss of

the building only once, such that the loss cannot exceed the building's total value. Figure 9.1 presents the total direct damages caused by coastal hazards by type of hazard for the 25 segments studied.

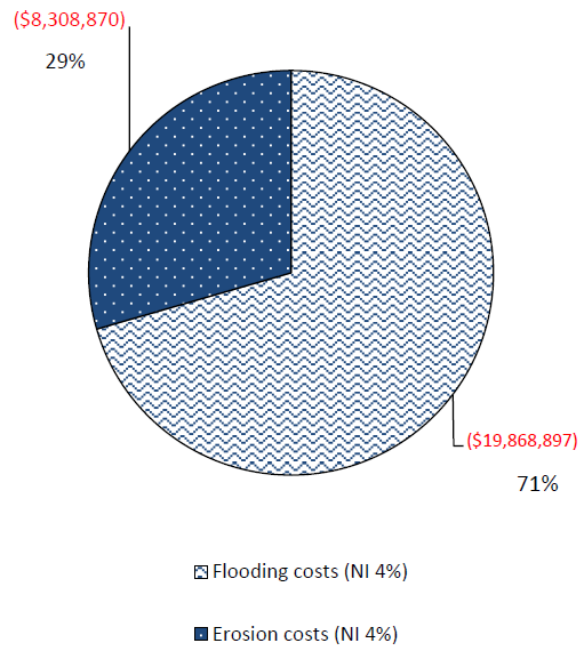


Figure 9.1 – Erosion and Flooding Costs of the Non-Intervention Options for the 25 Segments

This ratio between flooding and erosion damages is even more marked when costs are analyzed on a unitary basis (per linear metre). In this case, flood damages are, on average, 4.5 times greater than erosion damages.

Variability of costs

The second key finding is that erosion and flooding costs vary widely based on the at-risk assets and their associated economic activities.

Figures 9.2 and 9.3 summarize the results for the estimation of the costs of non-intervention for the 25 segments studied with respect to all issues identified and monetized. These costs include not only direct damages from erosion and flooding but also the economic, social and environmental costs of non-intervention.

Without intervention, the total costs for society are substantial amounting at more than \$825 million across the 25 segments examined for the next 50 years.

It is interesting to note the high variability of non-intervention costs across segments. The total costs of non-intervention vary from \$705M for the Anse du Sud segment (Percé) to about \$100,000 for the Gros-Cap Est segment (Îles-de-la-Madeleine). This variability is partly due to the importance of the assets in jeopardy (many buildings and municipal infrastructures) in certain segments in comparison with others. However, in segments where the anticipated non-intervention costs are high, as in Anse du Sud and La Grave, issues other than the built environment clearly boost the costs for non-intervention. Whether this concerns the presence of a tourism infrastructure or a site's heritage or recreational value, the impact of non-intervention on these variables often accounts for most of the non-intervention costs.

Figure 9.3 illustrates the high variability of non-intervention costs per linear metre (from \$123 to \$777,000). This shows that segment length is only a small part of the equation when it comes to explaining the disparity in anticipated impacts.

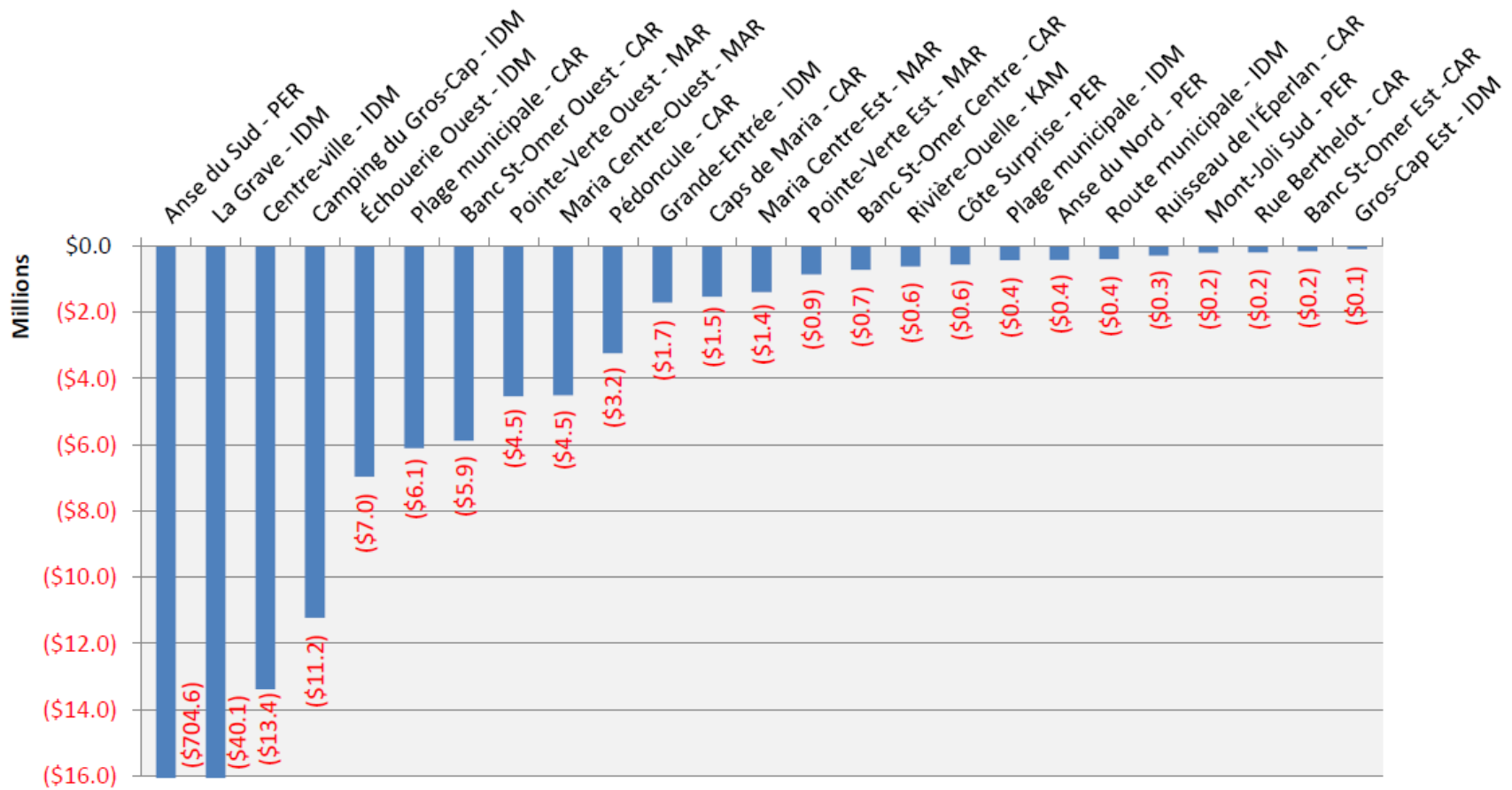


Figure 9.2 – Cost of the Non-Intervention Option by Segment

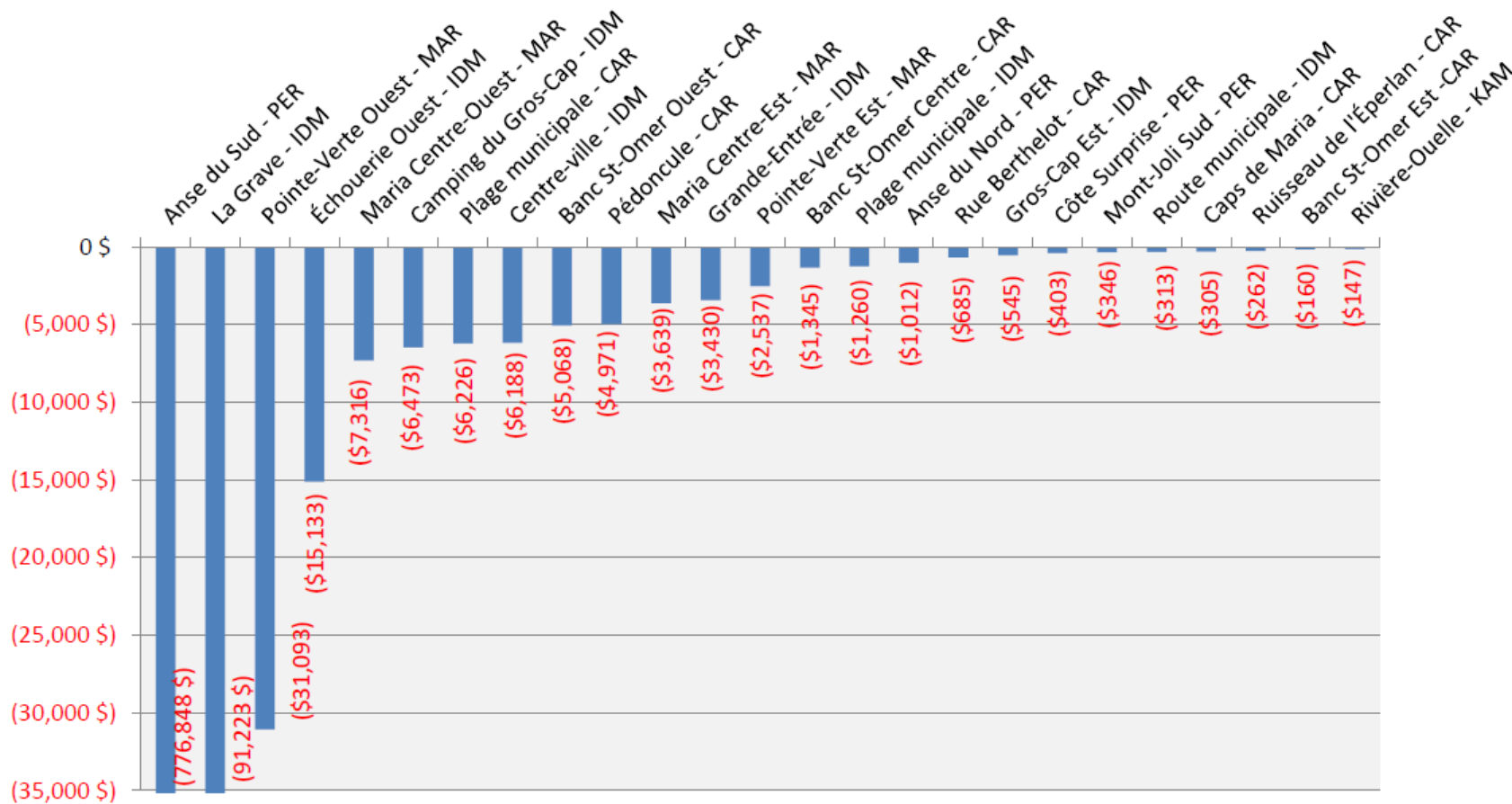


Figure 9.3 – Cost per Linear Metre of Coast for the Non-Intervention Option by Segment

9.2 PROFITABILITY OF ADAPTATION OPTIONS

The first finding concerning the adaptation measures arising from all CBA is that intervention is justified in most cases. As can be seen in Table 9.1, which presents the CBA results for all 25 segments in the study, intervention is economically justified in 19 of the study's 25 segments. Thus, at least one adaptation measure is beneficial in comparison with non-intervention (net benefits greater than 0) in 76% of cases.

Note that segments were selected based on asset vulnerability to hazards, a selection not necessarily representative of all coastal segments in Quebec. In other words, this analysis is not a basis for assuming that it would be economically viable to intervene along 76% of Quebec's coastline.

The results presented in the table also show that the net benefits of the most advantageous option vary considerably by segment. Thus, the segment that benefits most from implementation of an adaptation option is Anse du Sud, with over \$770M in benefits over 50 years. Conversely, certain segments like Banc de St-Omer Centre have much more modest net benefits over non-intervention (less than \$25,000).

In quite a few cases (44%), the profitability of intervention is marginal or unjustified. These highly diverse results illustrate that every site is unique, with its own specific issues, and that there is no way to know in advance whether an intervention is justified. Analyzing the profitability of an intervention depends first and foremost on a proper understanding of asset vulnerability, activities and usages.

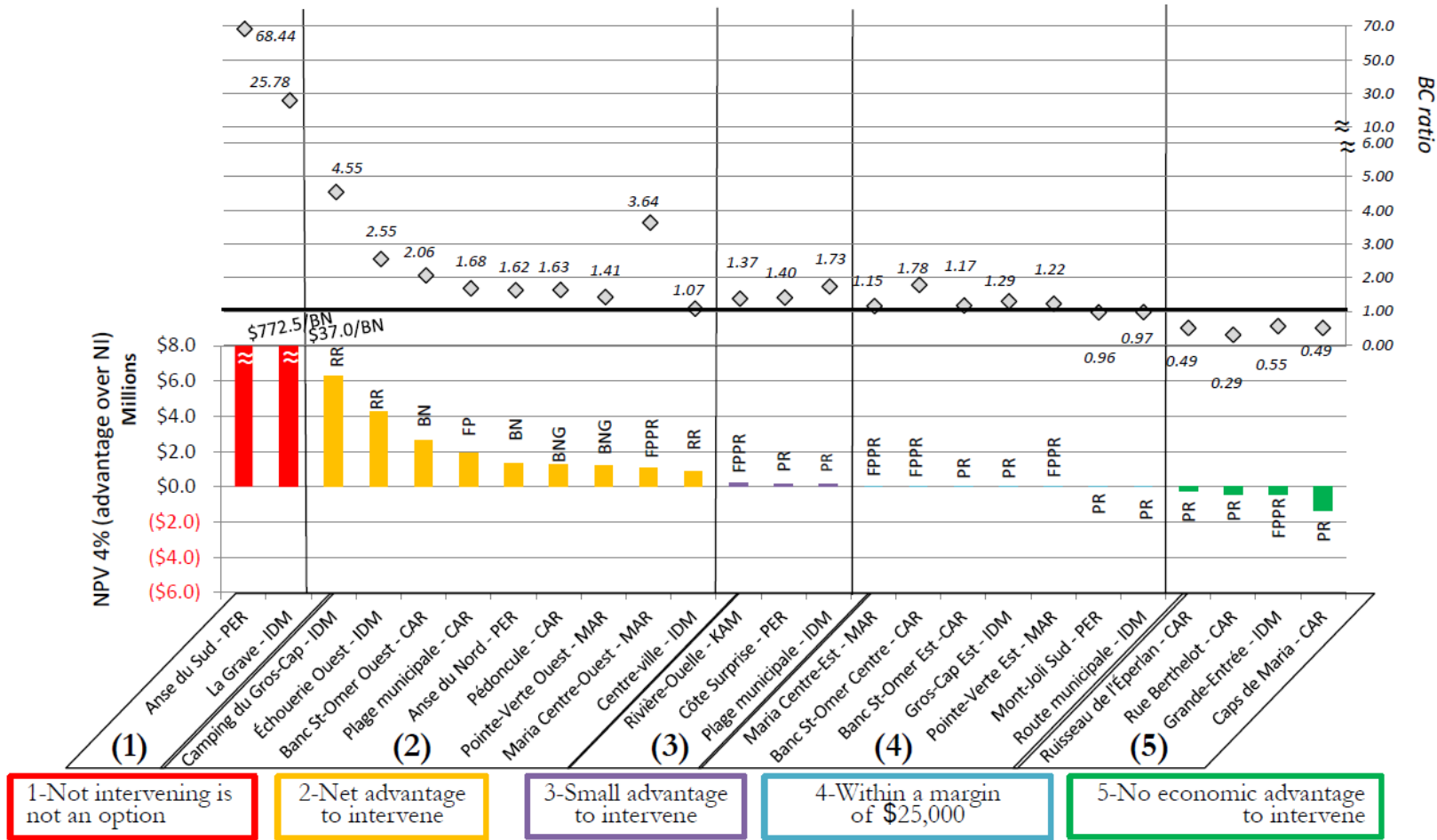
To better demonstrate this, Figure 9.4 provides a visual representation of CBA results by segment with net present value compared to non-intervention (net benefits) and the benefit-cost ratio. This representation can be used to group segments based on NPV.

Based on these two economic performance indicators, the segments examined were broken down into five groups described in the next sections: 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.

Table 9.1 – Most Advantageous Adaptation Option by Segment and Net Benefit Compared to Non-Intervention for the 25 Segments

Studied site	Segments	Dominant coast	Erosion	Flooding	Length (m)	Option	Net benefit compared to non-intervention (4 %)
Percé	Côte Surprise	Sedimentary cliffs	X		1,388	PR	\$158,833
	Anse du Sud	Beach terrace	X		907	BN	\$772,504,733
	Mont-Joli Sud	Sedimentary cliffs	X		605	NI	\$0
	Anse du Nord	Beach terrace	X		415	BN	\$1,216,670
Maria	Maria Centre-Ouest	Beach terrace	X	X	616	FPPR	\$1,033,960
	Maria Centre-Est	Beach terrace	X	X	382	FPPR	\$23,415
	Pointe-Verte Ouest	Beach terrace	X	X	146	BNG	\$1,216,670
	Pointe-Verte Est	Littoral spit system		X	341	FPPR	\$12,494
Carleton-sur-Mer	Banc de St-Omer Ouest	Littoral spit system	X	X	5,320	BN	\$2,655,426
	Banc St-Omer Centre	Beach terrace	X	X	540	FPPR	\$20,600
	Banc de St-Omer Est	Beach terrace	X		990	PR	\$17,646
	Rue Berthelot	Soft cliffs	X		286	NI	\$0
	Ruisseau de l'Éperlan	Soft cliffs	X		1,140	NI	\$0
	Plage municipale	Littoral spit system	X	X	780	FP	\$1,896,467
	Pédoncule	Littoral spit system	X	X	4,418	BNG	\$1,242,650
	Caps-de-Maria	Soft cliffs	X		5,406	NI	\$0
Îles-de-la-Madeleine	La Grave	Tombolo	X	X	440	PR	\$37,035,761
	Camping Gros-Cap	Sedimentary cliffs	X		1,734	BN	\$6,287,928
	Gros-Cap Est	Beach terrace	X		180	BN	\$17,585
	Échouerie Ouest	Sedimentary cliffs	X		460	RR	\$4,227,590
	Route municipale	Sedimentary cliffs	X		1,258	NI	\$0
	Plage municipale	Beach terrace	X		345	PR	\$147,561
	Centre-ville	Sedimentary cliffs	X		2,163	PR	\$842,052
	Grande-Entrée	Artificial	X	X	500	NI	\$0
Kamouraska	Rivière-Ouelle	Salt marsh	X	X	4,223	FPPR	\$189,308

Note : RR: Riprap; BN :Beach nourishment; BNG: Beach nourishment with groynes; PR: Planned retreat; FP: Flood proofing; FPPR: FP + PR; NI: Non-intervention



Note: BN Beach nourishment; BNG: Beach nourishment with groynes; FP: Flood proofing; PR: Planned retreat; FPPR: FP+PR; RR: Riprap

Figure 9.4 – Net benefits of the Most Advantageous Option Compared to the Non-intervention by Segment

9.2.1 First group: Not intervening is not an option

A first group of segments includes two sites: Anse du Sud in Percé and La Grave in Îles-de-la-Madeleine, where the potential erosion and flooding costs are very high due to the assets and tourism infrastructures that will be at risk over the next 50 years. These segments are regional attraction poles that support the local economy with recreational and tourism activities. Loss of these tourism drivers would have an economic impact of several tens of millions of dollars. In both segments, all interventions are more beneficial than non-intervention.

In terms of the type of options retained, soft engineering structures that maintain coastal access are the most beneficial, as they enhance the tourism offering as well as use value while averting the costs of coastal hazards. Implementing these structures would generate benefits of several tens of millions of dollars over non-intervention (see Figure 9.5). These options are also less costly than harder engineering structures, like concrete walls or rubblemound.

As regards the cost-benefit ratio, both segments in this group have very high ratios: for every dollar of costs, more than \$25 in benefits are expected. This reflects the importance of the benefits of adaptation.

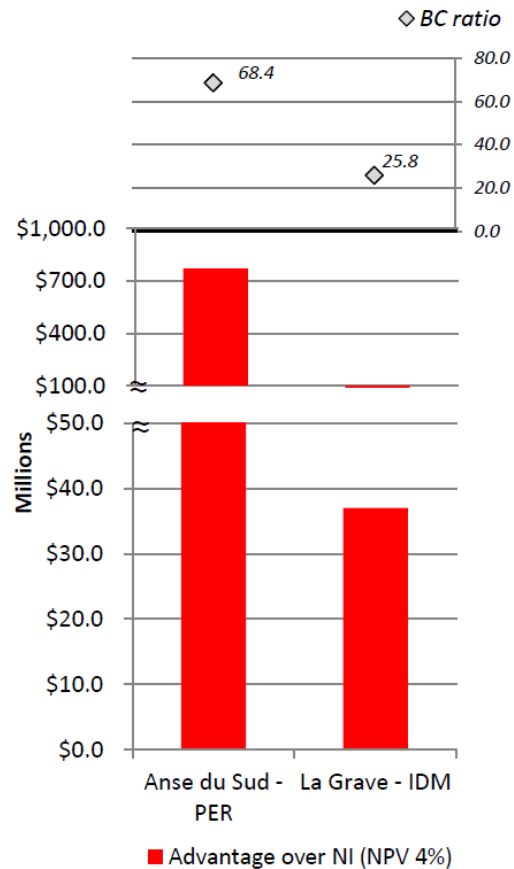


Figure 9.5 – NPV of the Most Beneficial Options Compared to the Non-intervention Option and Benefit-cost Ratios for the First Group of Segments

9.2.2 Second group: Net advantage to intervene

The second group consists of nine segments that will sustain significant damages from erosion and flooding, which will translate to major losses of coastal assets and their use. These damages are estimated at between \$420,000 and \$13M over the next 50 years.

In this second group, damages are high enough to justify intervention. These nine coastal segments can be broken down into three subgroups based on the favoured adaptation option and the type of coast.

- 1) Low-lying coastal segments with highly valuable at-risk assets. This subgroup is made up of four segments: Banc de St-Omer Ouest (Carleton-sur-Mer), Anse du Nord (Percé), Pédoncule (Carleton-sur-Mer), and Pointe-Verte Ouest (Maria).

These segments consist of beach terraces and coastal spits where the most economically beneficial options are beach nourishment with or without groynes (with net benefits ranging from \$1.2M to \$2.7M).

- 2) Cliff segments with highly valuable at-risk assets that justify riprap protection structures. These segments consist of soft or sedimentary cliffs with low elevations to which soft structures are ill-suited. All of these segments have at least one asset with a high economic or recreational value that will sustain heavy losses without intervention. All are located in Cap-aux-Meules, Îles-de-la-Madeleine: Camping du Gros-Cap, Échouerie Ouest and Centre-ville. Riprap protection generates a net benefit over non-intervention ranging from \$0.6M to \$6.3M, depending on the segment. For these three segments, the second most beneficial option is planned retreat, which safeguards most of the at-risk assets but is not as effective as riprap in preventing erosion damages.
- 3) Segments where engineering structures are too costly. This subgroup includes two segments, Plage municipale (Carleton-sur-Mer) and Maria Centre-Ouest (Maria), which are located on coasts of beach terrace. In these segments, flooding and erosion damages are not high enough to justify hard or soft engineering structures. However, the segments are home to residential and commercial buildings in at-risk areas that will sustain relatively significant damages. In both segments, flood proofing combined or not with planned retreat (as the case may be) would substantially reduce damages and generate a net benefit over non-intervention of between \$1.0M and \$1.9M.

For this second group of segments, the cost-benefit ratio varies from 1.07 for the Centre-ville segment (Îles-de-la-Madeleine) to 4.55 for the Camping du Gros-Cap segment (Îles-de-la-Madeleine). The low ratio for the Centre-ville segment is attributable to the substantial intervention costs, which reduce the ratio.

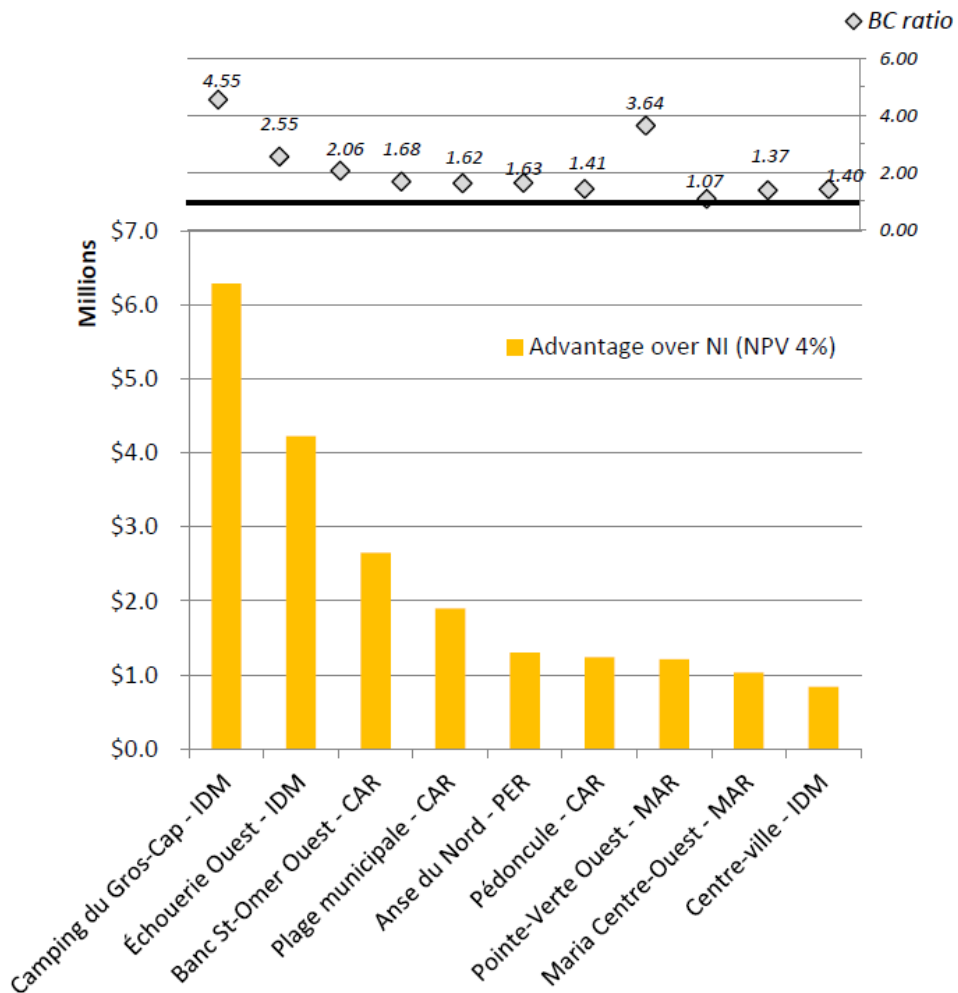


Figure 9.6 – NPV of the Most Beneficial Options Compared to the Non-intervention Option and Benefit-cost Ratios for the Second Group of Segments

9.2.3 Third group: Small advantage to intervene

The third group of segments covers cases where the CBA showed a relatively modest benefit for intervention. These segments are: Côte Surprise (Percé), Plage municipale (Îles-de-la-Madeleine), and Rivière-Ouelle.

This group of segments is characterized by relatively low anticipated damages from non-intervention (between \$400,000 and \$600,000) over 50 years that do not justify costly coastal interventions. All these segments are home to a major at-risk asset that will be threatened within the next 50 years.

The net benefit of the most beneficial adaptation option ranges from \$140,000 to \$200,000 (see Figure 9.7). In all three segments, this option is planned retreat of at-risk assets (residential and commercial buildings) and, for Rivière-Ouelle, a partial retreat combined with raising the aboiteau.

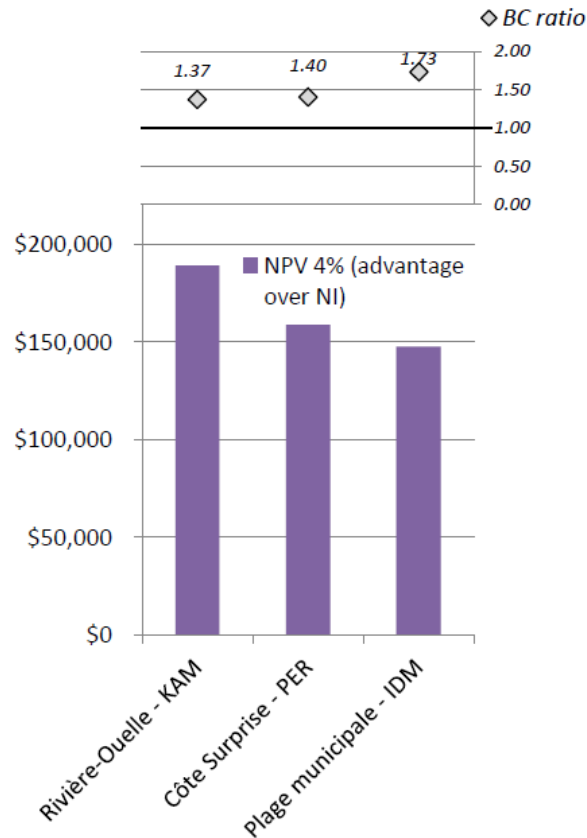


Figure 9.7 – NPV of the Most Beneficial Options Compared to the Non-intervention Option and Benefit-cost Ratios for the Third Group of Segments

The cost-benefit ratios for planned retreat are around 1.5, which is fairly low compared to those obtained in the previous segments. However, the results appear to be robust and the profitability of the measure is supported by the sensitivity analyses.

9.2.4 Fourth group: Within a margin of \$25,000

This group of seven segments includes cases where the NPV of the preventive adaptation option (flood proofing, planned retreat or both) is within a \$25,000 margin of the non-intervention option. This difference is positive for five segments and negative for

two others (see Figure 9.8). In all cases, none of the adaptation options involving a coastal intervention appears to be beneficial.

The segments in this group are as follows: Maria Centre-Est (Maria), Banc St-Omer Centre and Est (Carleton-sur-Mer), Gros-Cap Est (Îles-de-la-Madeleine), Pointe-Verte Est (Maria), Mont-Joli Sud (Percé), and Route municipale (Îles-de-la-Madeleine).

The main reason for the uncertainty surrounding the favoured option is the scope of the anticipated costs for non-intervention, which is less than \$900,000, except for Maria Centre-Est (\$1.4M). Where anticipated costs are low, an intervention is rarely justified unless the cost of the measure is even lower.

Notable explanatory factors for such low damages for non-intervention include the following:

- Most assets in these segments are quite far from the coast and are not at risk in the short or medium term.
- For certain assets, the cost of planned retreat or flood proofing exceeds the asset's actual value.

When the results of the CBA are within a \$25,000 margin, the sensitivity analyses often show a lack of robustness in the results. Changes in certain assumptions can then affect the results. For this group, the CBA results did indeed show greater instability during the sensitivity analyses. This makes it more difficult to conclude that intervention is economically justified. Nonetheless, other factors may influence the decision on whether to intervene, such as ethic factors.

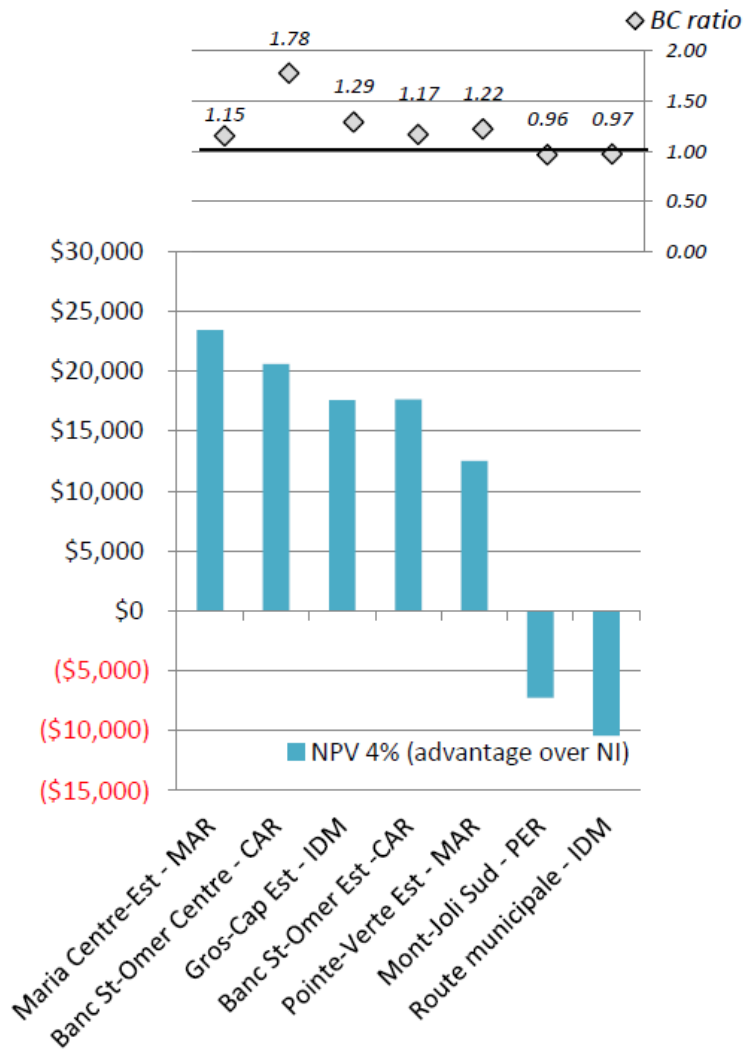


Figure 9.8 – NPV of the Most Beneficial Options Compared to the Non-intervention Option and Benefit-cost Ratios for the Fourth Group of Segments

9.2.5 Fifth group: No economic advantage to intervene

The fifth group covers segments where intervention seems clearly less beneficial than non-intervention. Four segments qualify for this category, with negative net benefits for adaptation options (-\$250,000 and -\$1.3M), as illustrated in Figure 9.9.

Segments in this group are: Ruisseau de l’Éperlan (Carleton-sur-Mer), Rue Berthelot (Carleton-sur-Mer), Caps-de-Maria (Carleton-sur-Mer), and Grande-Entrée (Îles-de-la-Madeleine).

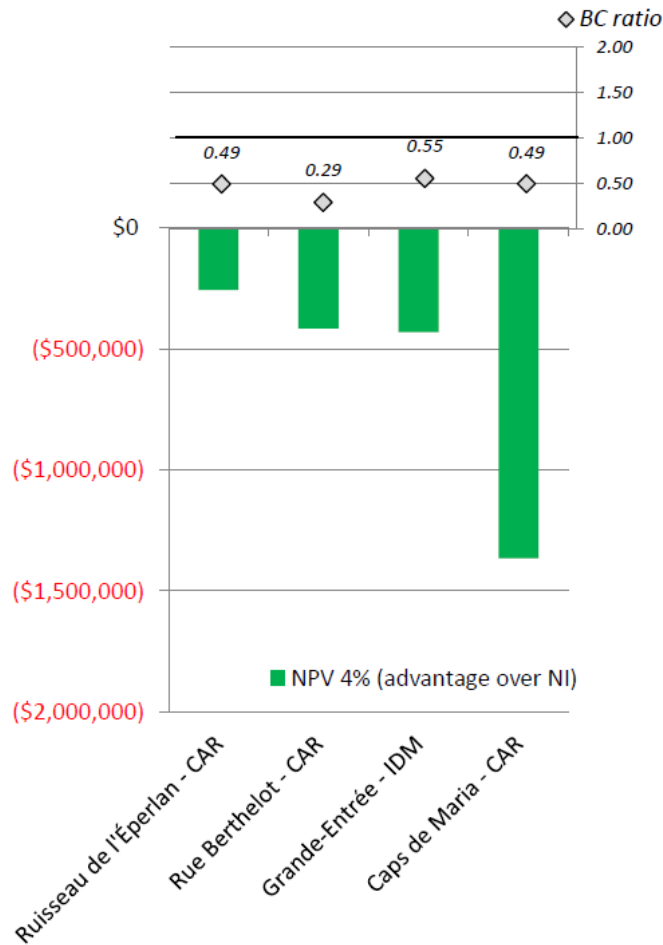


Figure 9.9 – NPV of the Most Beneficial Options Compared to the Non-intervention Option and Benefit-cost Ratios for the Fifth Group of Segments

Three of the four segments present similar characteristics in terms of hazards, type of coast, and assets at risk. The group's three segments for Carleton-sur-Mer are all located on soft cliffs with erosion rates on the order of a few decimetres per year and essentially home to primary residences and cottages with low property values.

The fourth segment in this group is a port area, one side of which is eroding rapidly, but that does not contain any high-value assets at risk within the study period.

As such, the low level of anticipated damages for these segments over the study horizon does not justify intervention.



10. LESSONS LEARNED

Lessons on both the study framework and its findings can be gleaned from the 25 CBA conducted in a wide range of settings with a variety of coastlines and issues. These lessons concern the factors that affect the relevance and usefulness of such a decision-making tool as well as the key components that play a determining role in the selection of an adaptation option.

10.1 COLLABORATIVE APPROACH

One of the main findings regarding the conduct of a study like this one concerns stakeholder involvement. When this study was designed, an approach based on cooperation with stakeholders was adopted. The approach aimed not only to establish a preferred channel for access to the information and data used to carry out the CBAs, but especially to guarantee that users and stakeholders would find the study useful, relevant and credible.

Concretely, the foundation for this cooperation was the creation of local steering committees for each of the study sites from the project's outset. Committee members were the main local stakeholders, including municipal employees, elected officials and representatives of various local and regional interest groups.

Throughout the study process, the research team stayed in constant contact with the committees. Members were involved at certain critical stages in the study to help the project team identify the adaptation options, working assumptions and anticipated

impacts as well as to validate the study's preliminary results. Relevant information and data were also shared between the project team and various committee members during informal discussions.

This privileged communication channel with local users and decision-makers was instrumental to enhancing the relevance and usefulness of CBAs in several respects. First, as mentioned earlier, without stakeholder collaboration, it would have been difficult, if not impossible, to access all the data and information essential to a thorough analysis. Furthermore, the transparent process reinforced the credibility of the research team and the project in the eyes of local stakeholders. This credibility led to the stakeholders appropriating the results which they will be able to share with the broader public. Since the stakeholders played an active role in the project, they are more likely to use and even defend the findings, as they were directly involved in establishing the assumptions and validating the results.

Creating a committee of provincial and federal public servants also expanded the reach of the findings within the departments and ministries responsible for managing and/or financing coastal development projects. Committee meetings contributed significantly to popularizing the concepts surrounding the CBAs for coastal environments in addition to demonstrating their relevance to an informed decision-making process on complex issues. The effects of the process are already a reality, notably for the Anse du Sud segment in Percé, where the CBA conducted by Ouranos was used as the economic justification for a project to carry out beach nourishment with pebbles. The findings were favourably received by all stakeholders, especially by political authorities.

10.2 LESSONS LEARNED WITH REGARD TO FINDINGS

A study of this scope, covering 25 coastal segments, should give rise to key lessons on general trends that dictate which option should be adopted in specific contexts. This exercise was carried out in the previous chapter when findings were categorized into five groups.

Although there is no simple or direct relationship between a type of coast and the preferred option for protecting it, the results do provide avenues for directing the analysis of different segment types. Classification into five groups is based on certain shared

characteristics. Nevertheless, every coastal segment is unique, with its own issues and dynamics. Given these elements, a rule of thumb cannot replace a CBA. This method of analysis is advisable when coastal segments are facing short-term erosion and flooding issues that threaten important assets, be they economic, environmental or social in nature.

The paragraphs below summarize the main lessons of this study, present avenues for future research, and formulate several recommendations for conducting CBAs in a coastal environment.

10.2.1 Range of impacts examined

By definition, a CBA aims to quantify all costs and benefits of the adaptation options examined in order to reflect, as accurately as possible, the study area's issues and how these affect the selection of the most advantageous option.

Conducting a CBA in a coastal environment requires an in-depth understanding and appropriate monetization of economic, environmental and social impacts. In a number of the segments studied, omitting such impacts would have led to different conclusions. The case of Anse du Sud (Percé) illustrates this point well. In Anse du Sud, intervention was shown to be justified by quantifying the impacts of non-intervention and the adaptation measures on tourism activity. Yet none of the adaptation options would have been economically justified had these economic impacts been omitted from the assessment. More generally, in most segments where coastal interventions were retained, multiple issues related to the impacts of hazards were considered. In short, erosion and flood damages alone are not always sufficient to justify costly coastal interventions.

To this effect, it would be relevant to improve scientific knowledge on the impact of coastal hazards and adaptation options on social and public health issues. Factoring in the insecurity and stress stemming from the uncertainty and dangers of coastal hazards may, for example, enrich the results of future CBAs in coastal environments.

10.2.2 Hydrodynamic assumptions

Building realistic erosion and flooding scenarios involving climate change is a complex exercise. Yet these scenarios are in large part responsible for the results of the CBA.

In terms of erosion, this study's approach is based on historical rates drawn from the periods deemed representative of future hydroclimatic conditions. However, in a context where certain parameters may accelerate or become magnified in comparison with historic periods due to loss of ice cover, among other reasons, the rates used may underestimate the future rate of coastal change and thus minimize anticipated damages.

The same applies to flooding scenarios where understanding is still limited as regards the joint probabilities of hazards associated with extreme water levels, waves and the variation in ice cover. The CBAs showed that flood damages are higher by far than erosion damages. It is therefore important to use well-established extreme water level scenarios in order to better anticipate asset vulnerability in at-risk areas.

10.2.3 Economic assumptions

Basic economic assumptions can also play a decisive role in the study's findings. The study period, the discount rate and economic growth assumptions may all favour one adaptation option over others. Note, in this regard, that the economic status quo assumption applied to simplify the analysis may lead to underestimation of the costs associated with damages and that it would likely be appropriate, in several cases, to review results in light of more realistic socioeconomic projections.

Adopting realistic assumptions that are coherent with the study environment is fundamental both for conducting the analysis and for its acceptance by stakeholders. Sensitivity analyses are also a means to ensure that the choice of assumptions has a minimal impact on selection of the most beneficial option.



11. CONCLUSION

Among the 25 segments examined, the analysis led us to determine that non-intervention was more beneficial than implementing an adaptation option for six segments (24%). For all other segments studied (76%) as part of the CBA project for Quebec coastal areas, it is more beneficial to take action than not.

Among the 19 segments where intervention is preferred over non-intervention, adaptation options without coastal structures are favoured in over half the cases (10 of 19), whereas hard and soft engineering structures represent respectively 12% and 24% of the most advantageous options for all segments in the study.

The results obtained for the 25 segments studied were categorized into five groups. Table 11.3 summarizes the key facts for these five groups of segments examined as part of this research project. In light of this classification, intervention is clearly beneficial in 14 of the 25 segments (groups 1, 2 and 3), or 56% of segments. In the remainder of segments (44%), the economic performance criteria do not warrant an intervention (see Figure 11.2). Although it is extremely difficult to generalize based on the case studies, the classification does allow for certain comparisons among segments based on their characteristics.

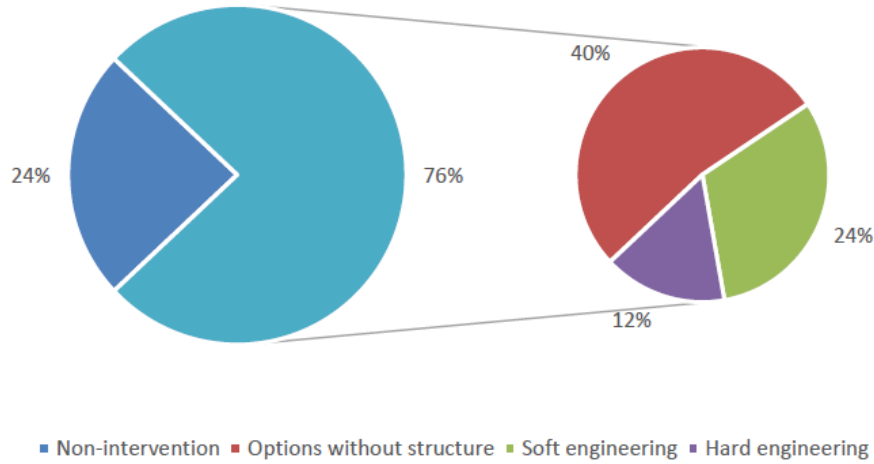


Figure 11.1 – Distribution of the Most Beneficial Options among the 25 Segments

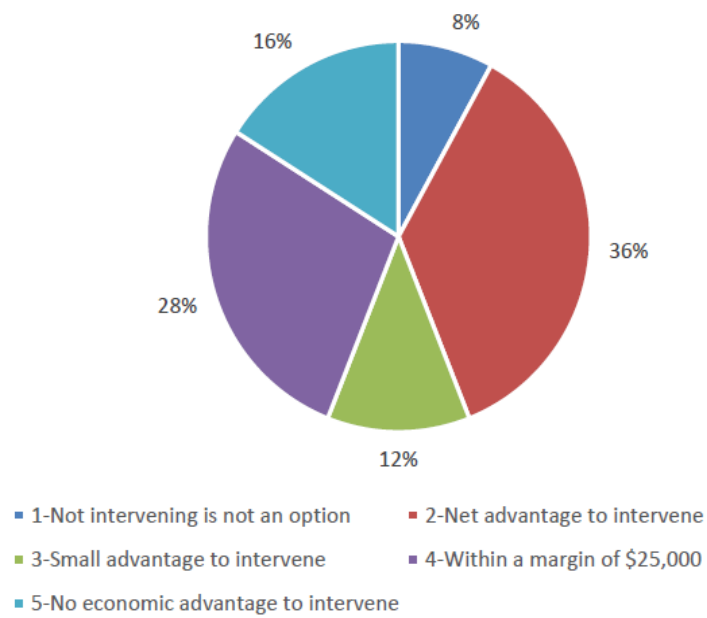


Figure 11.2 – Distribution of 25 Segments among the Five Groups

The study showed that certain factors affect the decision to take action or not and what type of action to take. Such factors include type of cost, the feasible technical solutions, existing protection, the length of the segment requiring protection, the value of assets at risk, the level of exposure to coastal hazards, the value of anticipated damages (including environmental and social costs), and the cost of implementing adaptation options.

Table 11.1 – Key Features of the Five Groups of Segments

Group of segments	NPV of most beneficial option compared to non-intervention NPV	Non-intervention cost per m of coast (NPV 4%)	Implementation cost of most beneficial options	Group features Type of coast/hazards – assets – options
1-Non-intervention is not an option (2 segments)	> \$37.0M	\$91,000–\$777,000	\$1.5M–\$9.4M	<ul style="list-style-type: none"> Regional or provincial assets at risk (tourism infrastructure) Direct advantages when adaptation options can contribute to improving coastal use All of the potential adaptation options are more beneficial than non-intervention
2- Net advantage to intervene (9 segments)	\$0.5M–\$6.3M	\$1,000–\$6,500	\$0.3M–\$12.5M	<ul style="list-style-type: none"> 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 beneficial options for low coasts with relative high value assets When the value of assets/uses is relatively high and the coast consists in eroding soft cliffs, riprap is the preferred option.
3- Small advantage to intervene (3 segments)	\$140,000–\$200,000	\$150–\$1,260	\$154–\$397,000	<ul style="list-style-type: none"> Segments typically composed of a major asset at risk over the study period (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, low-cost options being preferred.
4-Within an uncertainty margin of \$25,000 (7 segments)	(\$25,000)–\$25,000	\$160–\$3,700	\$29–\$330,000	<ul style="list-style-type: none"> Options without coastal structures or non-intervention are generally preferred in this group. Value of assets at risk and expected damages of non-intervention are low Factors favouring low non-intervention costs: low building density, little flood damages or none and delayed damages due to erosion.
5-No net economic advantage to intervene (4 segments)	< (\$25,000)	\$262–\$3,500	N/A	<ul style="list-style-type: none"> No 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 damages are very low.

This study showed that the CBA process and results enable stakeholders to develop a deeper understanding of the issues associated with coastal hazards as well as to assess their vulnerability to them. Stakeholders also achieve a greater understanding of how coastal interventions can affect the environment. A number of European governments have adopted CBAs as a standard and even regulatory practice before any coastal project is carried out because the process leads to local appropriation of issues complementary to study findings.

The use of CBA has not yet become standard practice in Quebec in coastal management. Thus far it has remained within the realm of research and is not often part of management processes by government organizations at any level. Yet this research project has shown the relevance of such a tool to decision-making regarding adaptation options for climate change, particularly when the issues warrant it. In coming years, it would be desirable for use of this tool to shift from the academic world to a more practical application by managers in public administration.



12. REFERENCES

- Bernatchez, P., Fraser, C., Friesinger, S., Jolivet, Y., Dugas, S., Drejza, S. and Morissette, A. (2008). Sensibilité des côtes et vulnérabilité des communautés du golfe du Saint-Laurent aux impacts des changements climatiques. Rimouski, Chaire de recherche en géoscience côtière - Laboratoire de dynamique et de gestion intégrée des zones côtières - Université du Québec à Rimouski, 256.
- BPR, Consultants Ropars, Groupe IBI/DAA (2014) Conception pour la reconstruction du mur de soutènement et de la promenade de Percé dans l'anse du Sud et pour la protection des berges dans l'anse du Nord. Rapport numéro 11522 (60ET), presented to Percé municipality, Gaspé, 104 p. + appendices.
- Didier, D., P. Bernatchez and A. Lambert (2014). Scénarios de submersion côtière pour la municipalité de Maria dans le cadre d'une analyse économique. Rimouski, Chaire de recherche en géoscience côtière - LDGIZC-UQAR for Ouranos, 33 + appendices.
- Horton, B. P., Rahmstorf, S., Engelhart, S. E., and Kemp, A. C. (2014). Expert Assessment of Sea-Level Rise by AD 2100 and AD 2300. *Quaternary Science Reviews*, 84, 1–6.
- Penning-Rowsell, E., Priest, S., Parker, D., Morris, J., Tunstall, S., Viavattene, C., Chatterton, J. & Owen, D. (2014). *Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal*. Routledge.