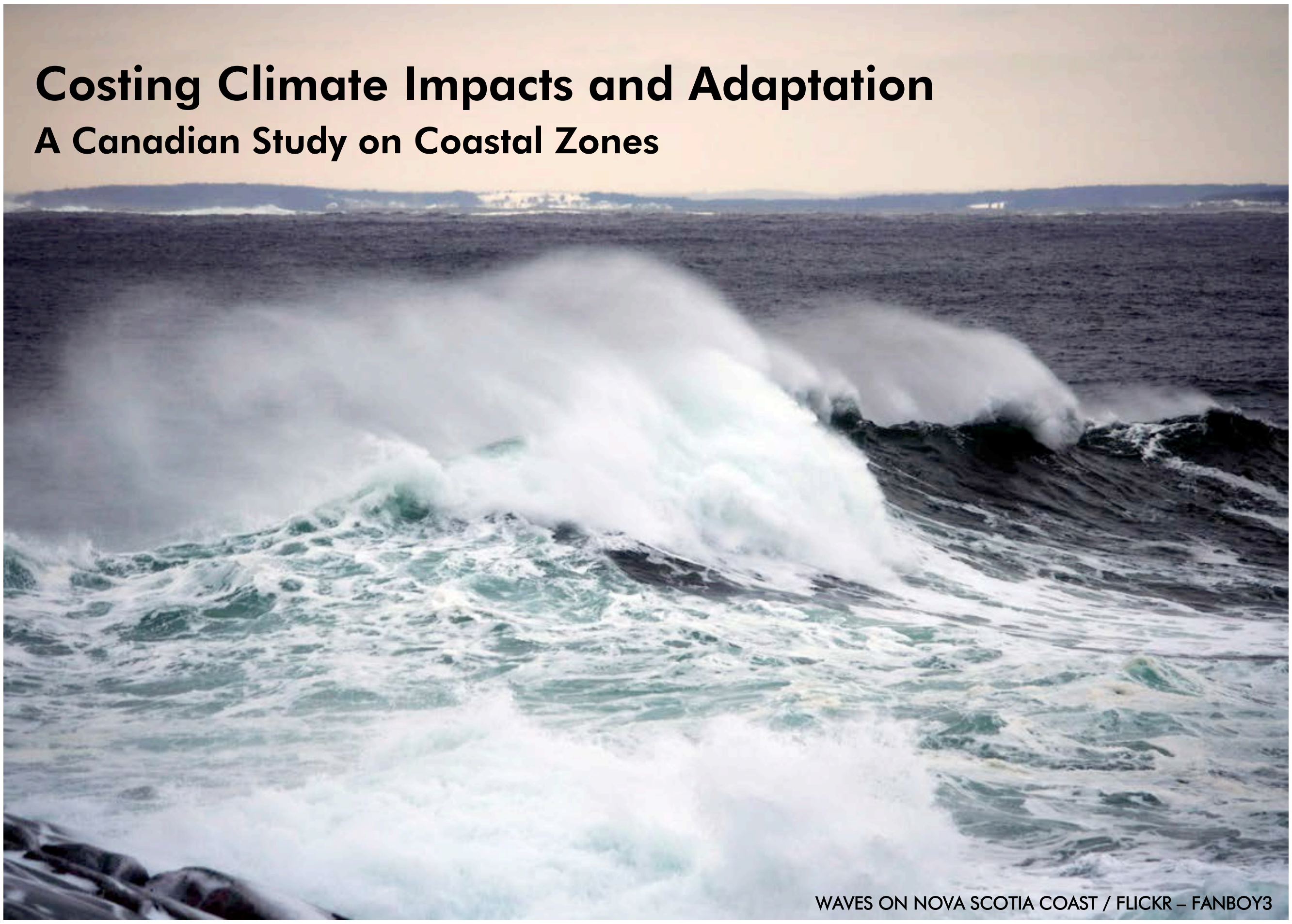
Costing Climate Impacts and Adaptation

A Canadian Study on Coastal Zones



WAVES ON NOVA SCOTIA COAST / FLICKR – FANBOY3

A REPORT COMMISSIONED BY THE NATIONAL ROUND TABLE ON THE ENVIRONMENT AND THE ECONOMY

Elizabeth A. Stanton

Marion Davis

Amanda Fencl

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SEI STOCKHOLM ENVIRONMENT INSTITUTE

For more information about this document,
contact Elizabeth A. Stanton at liz.stanton@sei-us.org

Stockholm Environment Institute – U.S. Center
11 Curtis Avenue
Somerville, MA 02144-1224, USA
www.sei-us.org and www.sei-international.org

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SECTION 1: EXECUTIVE SUMMARY

The future of Canada – and of the world – is likely to be shaped to a great extent by climate change: its direct impacts, the need to reduce carbon emissions, and the need to adapt to changing temperatures, precipitation patterns, and landscapes. Some of Canada's greatest vulnerabilities lie in its coastal zones, which are home to a concentrated population (38.3 percent of Canadians lived within 20 km of a coast as of 2001, on just 2.6 percent of the country's total area), economic centers, and valuable ecosystems.

The two great threats to coastal zones are sea-level rise and larger and more-frequent storm surges, which can destroy property, erode coastal land, salinate aquifers, and permanently flood low-lying areas. A seminal 1998 study of the risk posed by sea-level rise found that one-third of all Canadian coastline has a moderate or high level of sensitivity, yet very little research exists quantifying the likely economic impacts. Our study begins to fill that gap, combining a physical model of sea-level rise and storm-surge flooding with socioeconomic analysis and a review of existing research and policies related to climate impacts and adaptation.

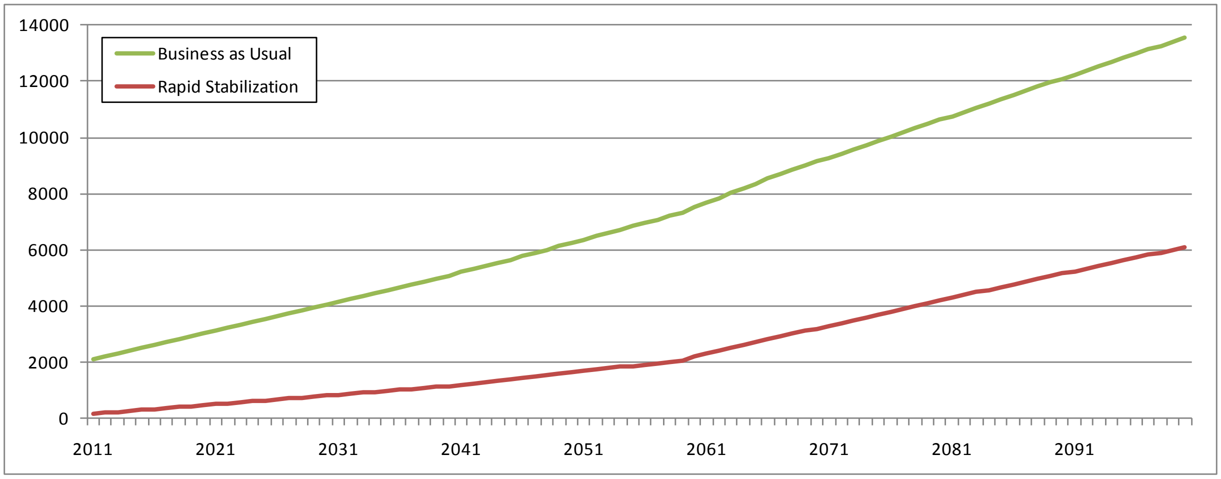
The physical model uses coastal elevation and tidal-range data to determine what land area would be inundated if sea levels rose above today's mean high tide. The level of detail is limited; Canada's coastline is rough and diverse, and our model uses average tidal ranges and relative sea-level rise rates for large stretches in each region, erring on the conservative side in estimating flood exposure. Similarly, areas already at or below sea level but protected by dikes or seawalls, such as agricultural land and parts of some cities, are excluded from our analysis. Sea-level changes unrelated to climate change – subsidence, uplift, and eustatic sea-level rise – are included in our analysis, often with substantial effect, but our economic analysis, which combines the results with Census and other data, only considers incremental damages related to climate change.

The economic impacts we quantify include damage to dwellings, agricultural land and buildings, and forests in Canada's coastal areas. We present them by province and territory, and for the nation as a whole, cumulatively and annually, using 30-year averages centered on 2025, 2055 and 2085. We consider four possible scenarios, based on the environmental and economic policy choices made: "business as usual," or a "rapid stabilization" of the climate; a "world-markets" orientation, or a more modest "local stewardship" economy. Then we overlay the potential impact of two adaptation measures on these scenarios – retreating from the most-exposed coastal areas, and curtailing development on land expected to become highly vulnerable as sea levels rise and storms increase. Finally, we analyze the distributional impact of damages, by province and territory, income level, and visible-minority status. We also consider the effects of coastal flooding on fresh-water reserves, but do not quantify their economic value.

Physical impacts

In several areas of Canada's coastline, sea levels have been rising and will continue to rise even if climate change contributes only minimally to the process. The relative sea-level rise in these areas –much of the Maritime Provinces and the Mackenzie Delta in the Arctic – renders them especially sensitive to climate change. Meanwhile, in other areas, sea levels are expected to drop. Thus in Manitoba, excluding climate-change impacts, we estimate that sea level will fall by almost 1 meter by the 2080s; in Newfoundland's north coast and Labrador, it will drop by 74 centimeters; in Ontario, by 47 centimeters; in Nunavut, by 30 centimeters. For Prince Edward Island and Nova Scotia, meanwhile, we estimate 29-centimeter rises in sea level unrelated to climate change; in the Yukon Territory, we expect a 33-centimeter rise, and on the Atlantic Coast of Newfoundland, 40 centimeters.

Executive Summary Figure 1: Land area exposed to sea-level rise and storm surge by climate-change (km^2)



Combined with those trends, climate impacts yield very different outcomes for different coastal areas. In our "rapid stabilization" scenario, Manitoba still sees a 78-centimeter drop in sea level; Newfoundland's north coast and Labrador, a 54-centimeter drop, and Ontario, a 27-centimeter drop. Meanwhile, sea level in the Yukon rises by 53 centimeters; in Prince Edward Island and Nova Scotia, by 49 centimeters, and on Newfoundland's Atlantic coast, by 60 centimeters – the largest increase anywhere. In our "business as usual" scenario, on the other hand, sea levels rise considerably more, with only Manitoba and Newfoundland's north coast and Labrador still seeing a net drop (36 and 13 centimeters, respectively), while five of the 20 areas we analyzed would see a rise of 90 centimeters or more (the worst would be Newfoundland's Atlantic coast, at 1.02 meters).

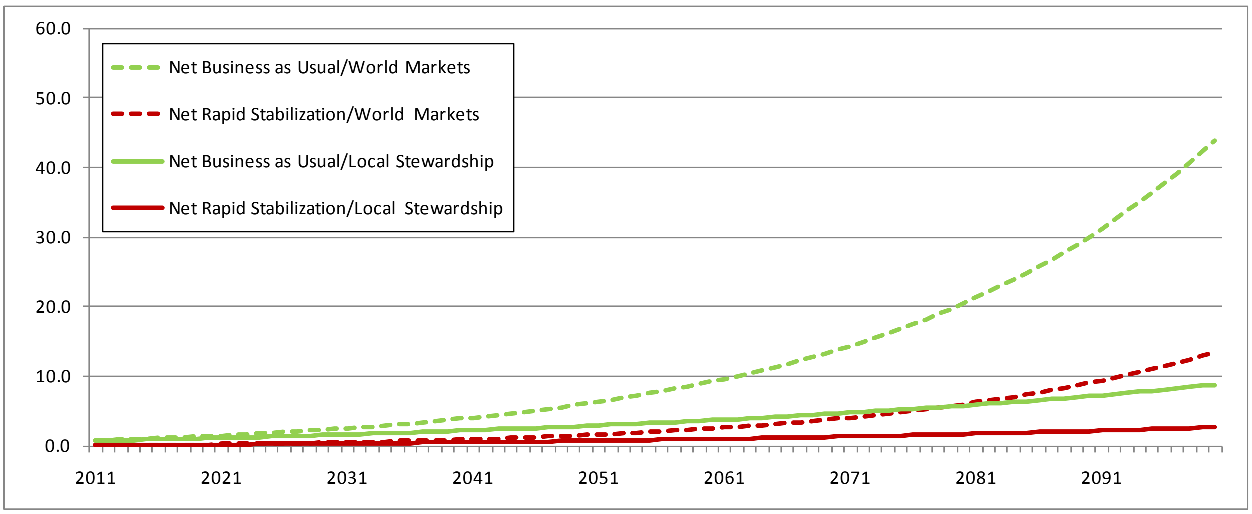
How that translates into flooded land and increased storm-surge exposure depends greatly on the topography: If the rising water quickly hits cliffs, as it would in the Bay of Fundy, the impact in terms of total land area flooded is minimal; if the water can advance freely, as in much of Nunavut and the Northwest Territories, much larger expanses could be taken over by the sea. Altogether, we estimate that in the rapid stabilization scenario, 903 km^2 of Canada's land area would be exposed to sea-level rise due to climate change by the 2080s, and an additional 3,820 km^2 would be exposed to storm surges (for a total of 4,723 km^2) due to climate change. In the business-as-usual scenario, the areas expand to 9,942 km^2 and 1,490 km^2, respectively (for a total of 11,433 km^2).

In both scenarios, Nunavut and the Northwest Territories together bear more than half the brunt of the flooding, but Ontario and Quebec would also suffer substantial impacts, with a total of 1,357 km^2 and 1,093 km^2 affected, respectively, by the 2080s in the business-as-usual scenario. The incremental flooding due to climate change in British Columbia, Nova Scotia, and Prince Edward Island, meanwhile, would be relatively small: 120 km^2, 106 km^2, and 41 km^2, respectively, by the 2080s in the business-as-usual scenario. In some places, however, storm-surge exposure is reduced precisely because some land that is now exposed will be permanently flooded. That is particularly notable in British Columbia, where we project sea-level rise due to business-as-usual climate change to inundate 142 km^2 of land, including 22 km^2 currently exposed to storm surges – resulting in the net 120 km^2 estimate. We must also stress that these estimates are net of flooding and storm-surge exposure caused by sea-level rise that is unrelated to climate change, which is considerable in many places.

Economic impacts

We estimate that annual economic damages to Canada's coastal areas from sea-level rise and storm surge inundation will range from $2.6 billion to $5.4 billion (in 2008 Canadian dollars) by the 2020s, and $7.3 billion to $48.1 billion by the 2080s – the equivalent, at that point, of 0.5 to 3.0 percent of the corresponding year's GDP. The role of climate change in those damages varies dramatically depending on the climate and socioeconomic scenario: It contributes $26.6 billion to the cost, or 1.6 percent of GDP, by the 2080s with the business-as-usual and world-markets scenario, whereas it only contributes $2.0 billion, or 0.1 percent of GDP, with the rapid-stabilization and local-stewardship scenario. (The economic scenario chosen plays an even bigger role than the climate scenario: Rapid-stabilization plus world markets leads to $29.4 billion in estimated annual damages, while business-as-usual plus local-stewardship cuts damages to $11.9 billion.)

Executive Summary Figure 2: Economic damages due to climate change (billions CAD2008)



Our estimates include economic damage to dwellings, agricultural land and buildings, and forests; they exclude damages to public infrastructure (such as roads, railways, ports, and public buildings); damages to non-residential private property and infrastructure (stores, factories, hotels, marinas); business losses due to sea-level rise and storm surges (reduced tourism revenue, the cost of an extended shutdown); relocation costs for people whose homes are destroyed (beyond the cost of replacing the dwelling); damages due to the salination of fresh water; damages from erosion; and ecosystem effects. Some of these costs are addressed in other studies within this project, but it is nonetheless important to understand that as with our flood estimates, our economic estimates are very conservative and limited to a narrow set of costs.

Executive Summary Table 1: Annual economic damages due to climate change

Total Damages (billions CAD2008)	2025	2055	2085
Net Rapid Stabilization/Local Stewardship	0.3	0.9	2.0
Net Rapid Stabilization/World Markets	0.4	2.1	7.9
Net Business as Usual/Local Stewardship	1.4	3.3	6.6
Net Business as Usual/World Markets	2.0	8.1	26.6
Damages as a share of each year's GDP			
Net Rapid Stabilization/Local Stewardship	0.0%	0.1%	0.1%
Net Rapid Stabilization/World Markets	0.0%	0.1%	0.5%
Net Business as Usual/Local Stewardship	0.1%	0.2%	0.4%
Net Business as Usual/World Markets	0.1%	0.5%	1.6%

Cumulatively, we estimate the value of 90 years' worth of damages from inundation due to climate change at $92.6 billion to $1.1 trillion, depending on the scenarios used. Applying a 3-percent annual discount rate (a commonly used way to estimate the current value of future costs), the cumulative costs drop to $17.6 billion to $182.2 billion – or 1.2 percent to 11.2 percent of the 2011 GDP in the corresponding economic models. Again, the choice of scenarios is crucial: The combination of business-as-usual plus world-markets accounts for about half of the high-end estimate, whereas rapid-stabilization plus local-stewardship only increases cumulative costs by 1.2 percent of GDP from the baseline projections (with today's climate and economy).

Executive Summary Table 2: Cumulative economic damages due to climate change

	Net Rapid Stabilization/ Local Stewardship	Net Rapid Stabilization/ World Markets	Net Business as Usual/ Local Stewardship	Net Business as Usual/ World Markets
Absolute damages (billions CAD2008)				
Discount Rate				
3 percent	17.6	47.5	73.5	182.2
0 percent	92.6	314.3	339.0	1,104.5
Damage as a share of 2011 GDP				
Discount Rate				
3 percent	1.2%	2.9%	5.0%	11.2%
0 percent	6.3%	19.4%	23.2%	68.1%

Looking in detail at the costs, we find that damage to dwellings is by far the largest share, along with damages to British Columbia (a finding discussed more below). We estimate total damages to dwellings due to inundation (climate-related and not) at $2.6 billion to $5.3 billion per year by the 2020s, and $7.3 billion to $48.1 billion by the 2080s, depending on the scenario. Rapid-stabilization plus local-stewardship only increases damages from the current climate and local-stewardship baseline projections by $2.0 billion in the 2080s, while business-as-usual and world-markets increases damages from the current climate and world-markets baseline projections by $26.6 billion by the 2080s. The large variation is due in part to assumptions about the average value of dwellings, which vary by socioeconomic scenario and year. Values are assumed to be proportional to per capita GDP, which declines over time in the local stewardship scenario, lowering the value of lost properties.

Economic damages to agricultural land and buildings, meanwhile, are higher in the local-stewardship scenarios, where the amount of total agricultural land is assumed to increase over time, than under world markets, where total agricultural land decreases. Nevertheless, damages to agricultural property and forests are on a lower order of magnitude than those to dwellings, and have little impact on total damages. Economic damages to forest areas differ by climate scenario, but not by socioeconomic scenario – with the worst outcomes in a business-as-usual model. Annual forest damages decline in all climate scenarios, partly due to model parameters – forest values stay constant over time – and partly due to topography. Provinces with large forest areas, like Ontario, tend to have negative sea-level rise and are less impacted by climate change.

We also estimate, but do not monetize, the impact of sea-level rise and storm surges on fresh-water reserves (climate-related and not): 4,571 km^2 to 6,205 km^2 of above-ground fresh water would be exposed to inundation by the 2080s, depending on the climate scenario (the vast majority in storm surges only). The fresh water area inundated due to climate change alone would range from 699 km^2 to 1,635 km^2, depending on the climate scenario.

Distributional differences

In terms of land area alone, Canada's flood exposure due to climate change is not substantial – 0.14 percent of the nation's total land, and much less of several provinces (Prince Edward Island is the hardest-hit, with 0.72 percent of its land area exposed). But what magnifies the economic impacts dramatically is that, as we mentioned at the outset, Canada's population and economic activity are concentrated in coastal areas. The more pronounced this concentration is in a province or territory, the greater the impact it will feel – which is why British Columbia, with more than half its population concentrated in the coastal Vancouver and Victoria metropolitan areas, is particularly exposed, with up to $1.9 billion in annual damages from climate change-related flooding by the 2020s and up to $25.1 billion by the 2080s, depending on the scenarios used. That means 91 to 97 percent of total annual damages due to climate change would occur in British Columbia, even though it has only 0.8 to 1.4 percent of the land exposed to inundation due to climate change.

Total damages (climate-related and not) in the Atlantic provinces together account for 17 to 33 percent of the national total, and the damages in these provinces grow smaller as sea levels rise. Economic damages in Manitoba, Ontario, and the Territories, meanwhile, do not contribute appreciably to national damages.

Visible minorities and the aboriginal population are over-represented among those exposed to inundation. In British Columbia, they account for more than 90 percent of the people living in areas exposed to inundation. Visible minorities make up 80 to 94 percent of the people exposed to climate-induced inundation overall; the vast majority of that population is in British Columbia, where they now make up 39 percent of the provincial population, and by the 2080s, this share is expected to grow to 49 percent. Aboriginal people make up 5 to 6 percent of the population exposed due to climate-induced inundation, with the greatest exposure in the 2020s in all scenarios. All or nearly all of the population exposed to climate-induced inundation in Nunavut and the Northwest Territories is Aboriginal; the same is true for more than one-third of the exposed population in Manitoba and more than 20 percent in Quebec. The Aboriginal population exposed to climate-induced inundation is 1.2 to 1.5 times this group's share of the Canadian population.

Low-income people are also disproportionately affected. The average household income for the residents of areas exposed to inundation is lower than for the general population in all provinces and scenarios, ranging from 55 to 59 percent of the average for Canada as a whole, depending on the time frame and scenario. However, there are substantial regional differences: In the Northwest Territories, the average income in areas exposed to inundation is a quarter of the general-population average; in Newfoundland, it's 57 to 75 percent, and in British Columbia, 64 to 71 percent. In most of the rest of the country, the income differences are much smaller. It is worth noting that substantial income gaps show up in all scenarios, even though the average household incomes for the total population vary almost fourfold by economic scenario, from $130,800 per year for Canada as a whole by the 2080s under local stewardship, to $488,100 under world markets (in the 2020s, they are $78,200 and $113,400, respectively).

Adaptation

In order to determine the best ways for Canada to adapt to sea-level rise and increased storm surges, we reviewed a wide range of studies at the national, province and local levels, mostly sponsored by Natural Resources Canada. We reviewed New Brunswick's Coastal Areas Protection Policy, the broadest and most comprehensive policy covering coastal development and adaptation measures that we could find, as well as British Columbia's legal framework for the protection of "development permit" and "environmentally sensitive" areas. In addition, we consulted directly with stakeholders.

We found two distinct – though often overlapping – approaches. On the ground level, especially in local case studies, there is a focus on direct responses to sea-level rise and increased storm-surge risk, grouped in three categories: retreat (abandoning property, returning the most vulnerable areas to nature), accommodation (zoning restrictions, setbacks, lower-value land uses, elevated construction, flood warning systems), and protection (sea walls, dikes and other barriers, but also nature-focused approaches such as restoring dunes and wetlands that act as natural buffers). On a policy level, meanwhile, the focus has been on building adaptive capacity across the country, with key recommendations such as identifying "best practices" and model policies; ensuring that local decision-makers have continuous access to adaptation expertise and to relevant scientific and technical information; and engaging and educating the public. In addition, several provinces are developing or refining legal frameworks for the protection of coastal areas, to ensure that local authorities have the power and guidance to act.

The direct responses recommended vary considerably by location and circumstances, but there is a strong preference for working with nature, rather than against it, whenever possible. Some studies have suggested retreating from highly vulnerable areas, but that is often not the favored response – especially not for privately owned land that is already developed or considered usable. Armoring the coast, meanwhile, is considered problematic by scientists and is very expensive, but it tends to be property owners' first choice. Dikes and seawalls have been in place for as long as centuries in some areas, but some parts of the coast (in New Brunswick, e.g.), have seen a rapid "hardening" of the coast in the last two decades, with new seawalls, rip-rap mounds and other structures all along the water. Recommended middle grounds include accommodation – setting houses back as far as possible from beaches and cliffs, building on stilts – and the protection and restoration of dunes, wetlands and other ecosystems that serve as natural barriers.

We quantified the impact of two possible adaptation measures: sensible development planning, and strategic retreat from the most affected areas. The first involves building no additional homes in areas exposed to inundation by 2100 in this model, a zero-cost measure in our model (unearned property tax revenue, possible reimbursements to property owners, and unrealized development value are not considered here). The second involves abandoning areas as they enter the zone at risk of storm-surge inundation, at a cost equal to the value of existing homes in those areas. Both measures are strong versions of existing and proposed policies designed to minimize the extent of potential damage; we considered them individually, and combined.

Annual climate-induced damages in the 2080s in the business-as-usual/world markets scenario are more than 0.6 percentage points of GDP lower with sensible development planning; these damages fall from 1.64 percent of GDP to 0.07 percent with strategic retreat, and to 0.04 percent with the combined policies. In the business-as-usual/world markets scenario, assuming a 3-percent discount rate, cumulative damages fall from 11.2 percent of 2011 GDP to 7.8 percent with sensible development planning, 0.6 percent with strategic retreat, and 0.4 percent with the combined policies. In the business-as-usual/local stewardship scenario, cumulative damages fall from 5.0 percent of 2011 GDP to 3.9 percent with sensible development planning, 0.2 percent with strategic retreat, and 0.1 percent with the combined policies.

The role of sensible development planning cannot be overstated. In the business-as-usual/world markets scenario, this measure alone lowers cumulative climate-induced future coastal damages by over 30 percent (at a 3-percent discount rate). It is important to recall that these estimates include only residential property, agricultural land and buildings, and forest land. If new development along low-lying coastlines also includes stores and hotels, roads and sewage lines, factories and power plants, damages could be far higher – and the savings from this measure that much greater. Strategic withdrawal from areas as they begin to flood lowers cumulative climate-induced damages even more, by 95 percent. Without this adaptation measure, home-owners rebuild each time they sustain damage in a storm. With this measure enforced as public policy, damaged homes are abandoned and the price of rebuilding them is invested instead into homes in less-risky areas. With both adaptation measures in effect, cumulative climate-induced damages are just 3 percent of the costs without adaptation.

Policy recommendations

The potential property damage to coastal Canada from climate change is serious, and the people most affected are likely be poorer than average and disproportionately from visible minority or Aboriginal populations. A few simple, straightforward adaptation measures would greatly reduce these damages; if public planners embrace – and enforce – forward-thinking zoning laws appropriate to Canada's future coastline, much property damage can be avoided.

The results of this study have clear policy implications for Canadian national, regional and local authorities. Coastal damages from climate change can be reduced by means of forward-thinking planning and zoning. Here we offer several policy recommendations regarding improved accuracy of future sea-level rise studies, and the implementation of adaptation measures similar to those quantified in this report.

- Develop "model" policies that incorporate these strategies, and adopt them at the province and territory level, with protected zones defined by law (e.g. all beaches, dunes, and coastal wetlands, plus a restricted-development area within 30 meters of those zones, as is New Brunswick's policy), and the ability for local authorities to impose further, but not fewer, restrictions. To prevent a maladaptive rush to develop coastal land prior to implementation, consider a development moratorium in the affected areas while policies are being drafted, and do not allow the adoption process to stretch out for more than one year – even if a choice is made to phase in the strictest measures.

- Develop more precise sea-level rise and storm-surge projections for the entire Canadian coast, with a special focus on densely populated areas, and develop a system to regularly update the data and monitor the coastal landscape for erosion and other issues. Greater precision in these estimates will require better elevation data, and a large, well-funded national study to enable far greater local detail in the physical model. Areas at or below sea level should be analyzed more closely, to gauge their exposure to sea-level rise and storm surges and the effectiveness of dikes and other existing barriers.
- Strengthen province/territory and local capacity to develop and implement adaptation plans by continuing to fund projects such as the Regional Adaptation Collaboratives; bringing together land-use and environmental experts and enforcers within government (as New Brunswick has done in its Department of Environment); making it easy for local authorities to obtain crucial information and call in experts to assist them; and funding training opportunities.
- Educate and engage the public, directly (through the media, websites, etc.) and especially through businesses and professionals likely to interact with home-owners and developers and with a possible stake in mitigating losses – property insurers, banks, real-estate agents, construction companies, architects, landscapers.
- Seriously consider the implications of economic and environmental choices beyond coastal-zones management: A local-stewardship economy would sharply reduce climate-related losses in the future, but it would require a major shift in priorities. Rapid stabilization of greenhouse gas emissions cannot be achieved by Canada alone, but Canada can choose its role in reducing emissions, and either be a leader, or a straggler. We recommend fostering nationwide debate of these issues.

The impact of climate change on rising seas and storm surges has already been set in motion. The inundation of Canada’s coastlines is almost certain to be at least as extensive as shown here in the rapid-stabilization scenario, and most likely, far worse. Global emissions of greenhouse gases are accelerating at what will be a great cost of Canada and to nations around the world. There is a role for Canada to play in reducing these emissions and in negotiating reductions in other countries. There is also a role for it to play in protecting its own residents and assuring that future damages will be as small as possible through adaptation investments. Careful development planning today will go a great way towards limiting future damage costs.

SECTION 2: INTRODUCTION

This study estimates economic damage to dwellings, agricultural land and buildings, and forests in Canada's coastal areas due to climate change-related sea-level rise and storm surges. We present results by province and territory, and for the nation as a whole, cumulatively and annually, using 30-year averages centered on 2025, 2055 and 2085. We examine four different future scenarios, exploring higher and lower emissions as well as greater and lesser emphasis on a globally integrated economy. Then we overlay the potential impact of two adaptation measures on these scenarios – retreating from the most-exposed coastal areas, and curtailing development on land expected to become highly vulnerable as sea levels rise and storms increase. Finally, we analyze the distributional impact of damages, by province and territory, income level, and visible-minority status. We also consider the effects of coastal flooding on fresh-water reserves, but do not quantify their economic value.

The report is organized as follows:

Section 2 provides background regarding the impacts of climate change on Canada's coastal zones, including previous economic damage assessments, and current and proposed adaptation initiatives. This section also lays out the temporal and spatial boundaries of this study, and the future scenarios and categories of damages considered in our quantitative analysis.

Section 3 is a detailed methodology.

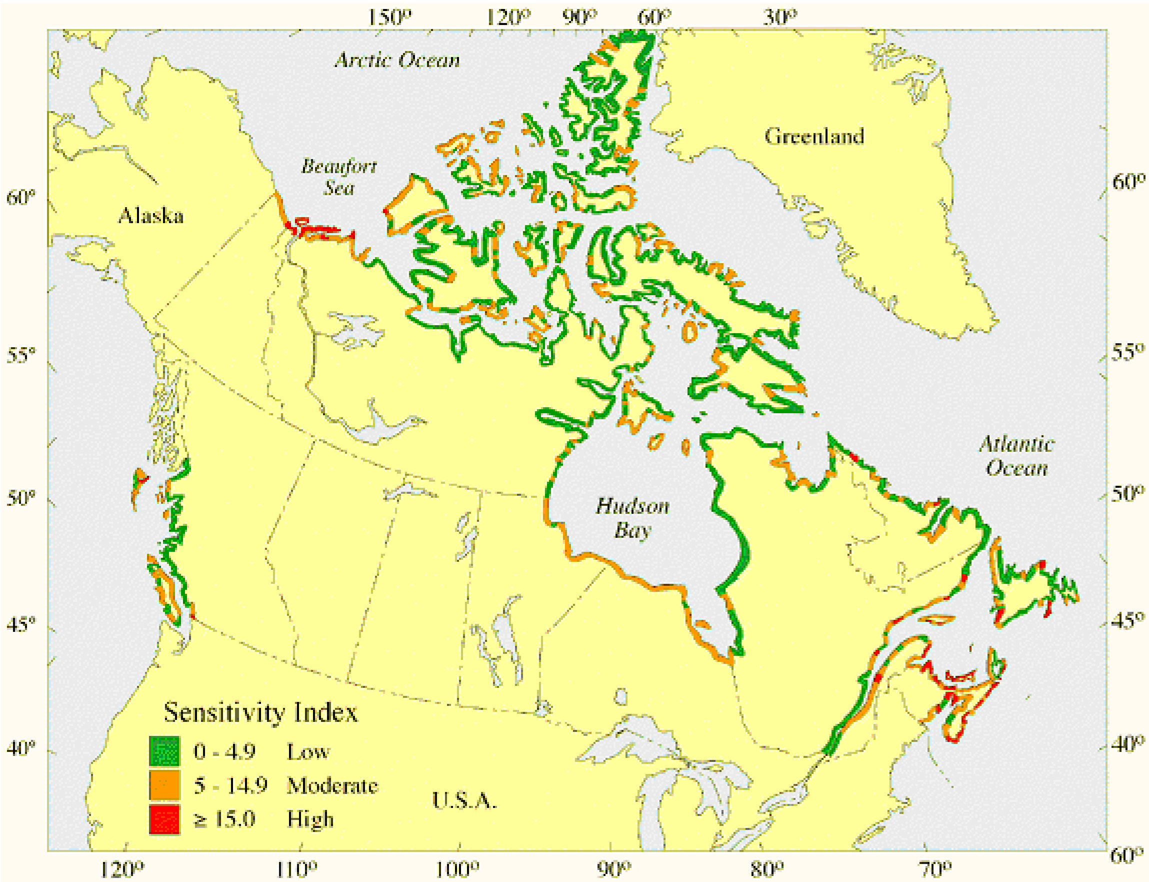
Sections 4 and 5, respectively, report physical (land area inundated) and economic damages, as well as the impact of proposed adaptation measures.

Section 6 presents a distributional impact analysis (by province/territory, visible-minority and Aboriginal status, and income) and discusses the policy implications of our economic analysis.

2a. Current Climate Sensitivity of Canadian Coastal Zones

For Canada, the vulnerability of coastal areas to sea-level rise, storm surges, and erosion is one of most serious issues arising from climate change. Coastal zones are home to a concentrated population (38.3 percent of Canadians lived within 20km of a coast as of 2001, on just 2.6 percent of the country's total area); they are also economic centers, and they contain valuable ecosystems. A seminal study of the risk posed by sea-level rise (Shaw, Taylor, Solomon et al. 1998; Shaw, Taylor, Forbes et al. 1998) found that one-third of all Canadian coastline has a moderate or high level of sensitivity. Very little research exists quantifying the likely impacts of climate change on Canada's economy; the results of this study will begin to fill that gap.

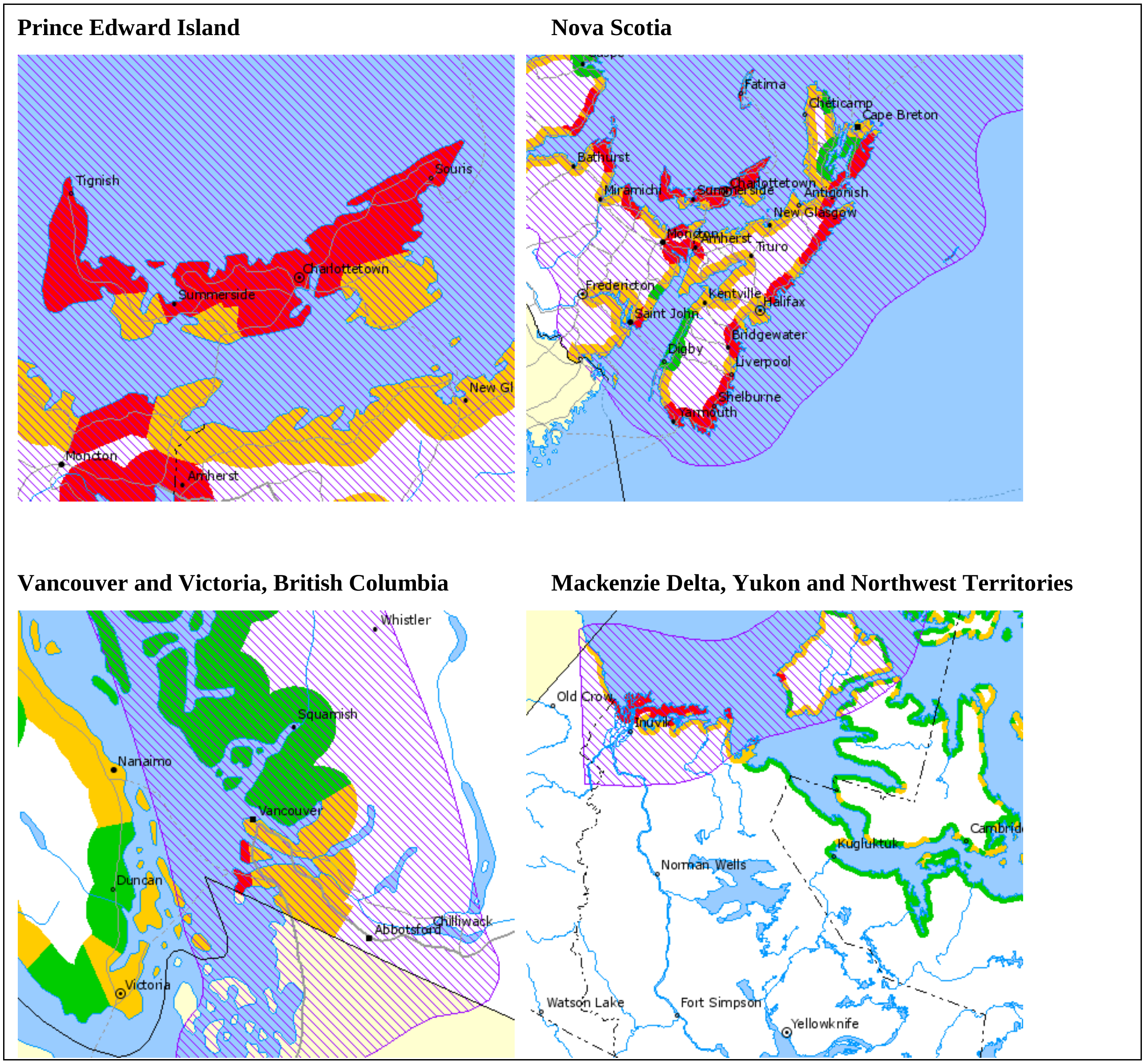
Figure 1: Sensitivity of Canada's coastline to sea-level rise



Sources: Shaw et al. (1998; 1998) and Natural Resources Canada (ND-e), image available online at http://gsc.nrcan.gc.ca/coast/sealevel/images/sens.gif.

In several areas of the coastline, sea levels have been rising and will continue to rise even if climate change contributes only minimally to the process. The relative sea-level rise in these areas – much of the Maritime Provinces and the Mackenzie Delta in the Arctic – renders them especially sensitive to climate change. Eighty percent of the Nova Scotia, New Brunswick and Prince Edward Island coastlines were classified as having moderate or high sensitivity to sea-level rise (Shaw, Taylor, Forbes et al. 1998; Shaw, Taylor, Solomon et al. 1998). In addition, Canada's most populous coastal zone – the Vancouver/Victoria area in British Columbia – faces a special risk because of its higher population density.

Figure 2: Areas especially sensitive to sea-level rise



Source: Natural Resources Canada(ND-b); annotated map available online at http://atlas.nrcan.gc.ca/site/english/maps/climatechange/potentialimpacts/coastalsensitivitysealevelrise/1.
Note: High sensitivity = red; yellow = moderate; green = low; shaded areas are currently experiencing subsidence not related to climate change.

2b. Literature Review

Very few studies exist of the economic impact of climate change on Canada's coastal zones. The only studies providing damage cost estimates on a national scale are international models using a top-down methodology – that is, starting from a model of global economy and climate system. Most regionally disaggregated integrated assessment models include Canada as part of an "other high-income" region, but few report Canada-specific results, and still fewer results specific to Canada's coastal zones (see Bosello et al. 2007; Narita et al. 2009; Robert J. Nicholls et al. 2008; Drozdz 2008). The accuracy of top-down modeling results for use as country- and damage-specific estimates is highly questionable, given that the main purpose of these models is to estimate the scale of projected global damages and provide regional comparisons.[1]

There have been national studies of the coastline's sensitivity to sea-level rise (Shaw, Taylor, Forbes et al. 1998; Shaw, Taylor, Solomon et al. 1998) and scientific assessments of climate change in Canada that included sections on coastal zones (Natural Resources Canada 2004; Environment Canada 1998; Lemmen et al. 2008). Similarly, the Arctic Climate Impact Assessment (2004) looked at the effect of sea-level rise on the greater Arctic region. None of these studies addressed economic impacts in any detail.

Numerous Canadian regional and local sea-level rise impact studies exist (see, among others, Robichaud and Bégin 1997; S. Solomon 2008; Walker and Barrie 2004; Walker et al. 2007; Bornhold 2008; Savard et al. 2008). Environment Canada (2006) research on sea-level rise in New Brunswick estimated property losses in the event of a 2.5-meter storm surge. McCulloch et al. (2002) analyzed several scenarios of sea-level rise and storm surge flooding for Prince Edward Island. The latter studies both found damages in the hundreds of millions of dollars.[2] The DINAS-COAST DIVA model for Canada estimates aggregate damages from coastal flooding, land loss, salinity intrusion, and migration costs ranging from hundreds of millions to $60 billion in the 21st century, depending on the projected climate scenario (Drozdz 2008).

2c. Overview of Existing Adaptation Initiatives

In an effort to identify the best examples of adaptation planning in response to sea-level rise and increased storm surges, we reviewed a wide range of studies, including several compilations (Natural Resources Canada ND-a; Mehdi et al. 2006; Canadian Institute of Planners ND; Indian and Northern Affairs Canada 2009), and contacted national- and regional-level leaders in this field directly (Proulx 2010; Hill 2010; Hudson 2010). We found a substantial body of work to draw from, most of it sponsored by national agencies, especially Natural Resources Canada; despite a broad recognition of the importance of local leadership and policies (such as municipal planning and zoning) in effective adaptation, however, local involvement in those projects has often been limited, or only advisory.

With the exception of Halifax, most studies have also focused on smaller cities and rural areas, including Aboriginal communities, reflecting the nature of most of Canada's coastline but leaving a potential gap in the understanding of how major coastal cities may need to adapt. More promising models may be available at the regional and province levels, especially in New Brunswick, where a coastal protection policy (2002) has been in place for eight years and extensive research – on the policy and on adaptation options in general – has been conducted. British Columbia's legal framework for the protection of "development permit" and "environmentally sensitive" areas is also of interest. In addition, new Regional Adaptation Collaboratives (Natural Resources Canada ND-d, 2010b) being launched this year are expected to greatly increase province- and region-level activity in this field.

Figure 3 outlines our selected examples; see the source notes below for details of the documents reviewed for each example.

[1] For a description of these models and some of their key limitations, see Stanton, E. A., F. Ackerman, and S. Kartha (2009), "Inside the Integrated Assessment Models: Four Issues in Climate Economics," *Climate and Development* 1.2.

[2] Throughout this report, dollars refer to CAD.

Figure 3: Coastal adaptation initiatives

Geographic Scope	Adaptation Initiative	Description
National	Canadian Institute of Planners and Natural Resources Canada[a]	Natural Resources Canada and the Canadian Institute of Planners have collaborated since 2004 to build capacity among local planners to adapt to climate change. As part of this process, five municipal case studies were sponsored, three involving sea-level rise: Delta (BC), Graham Island (BC), and the Northumberland Strait (NB). Extensive resources have been provided to gauge vulnerability and identify adaptation needs, with scientists and planners traveling to communities and helping spur local initiatives (see below). In addition, CIP has worked to develop a curriculum to train working planners and educate aspiring planners at universities.
	Natural Resources Canada Regional Adaptation Collaboratives[b]	As part of an $85.9 million Canadian government investment, Natural Resources Canada has set up a $30 million Regional Adaptation Collaboratives project and is spending $5 million to develop sharable Tools for Adaptation. Grant-funded projects are now being announced: British Columbia unveiled its program in late January, and the Atlantic Regional Adaptation Collaborative was unveiled in April.
	Canadian Climate Impacts and Adaptation Research Network (C-CIARN) Coastal Zone[c]	A five-year project (2002-2007) hosted by the Earth Sciences Sector, Geological Survey of Canada. Working with other C-CIARN offices and various organizations, C-CIARN Coastal Zone held workshops across Canada on climate change impacts and adaptation, working by region, often using site-specific examples (e.g. beach protection in Kingsburg Beach, NS), and supporting local initiatives. A final 'state-of-play' report identified several ongoing needs: access to data to aid coastal stakeholders; updated and expanded data on climate-induced sea-level rise, among others; climate scenarios and predictive models; and tools, guides and best practices.
Provincial/ Regional	Impacts of Sea-Level Rise and Climate Change on the Coastal Zone of Southeastern New Brunswick[d]	A multi-partner study led by Environment Canada, including a case study by the NRC/CIA project (see above). Rising sea-levels in southeastern New Brunswick have already caused significant damage, mostly due to flooding and erosion, and in the winter, when the Gulf of St. Lawrence is partially covered by sea ice, rising water level could push the ice cover inland, harming houses and infrastructure. The adaptation part of the study examined past community responses to sea-level rise and storm surges, perceived future threats, planning, and best practices. Overall, it found a lack of information on possible techniques and practices, insufficient resources, and a lack of effective local planning and coastal development management tools. A decision-making framework was developed to help address these issues, with a process for choosing appropriate adaptation strategies for specific locations.
	Addressing Climate Change Adaptation: A Collaborative Approach in Support of the Nunavut Climate Change Adaptation Plan[e]	Multi-year joint effort by the Canadian Institute of Planners, the Government of Nunavut, the Ittaq Research Centre, and federal agencies, slated for completion in March 2011. The goal is to build capacity among Nunavut communities for climate change adaptation planning. Initiatives include an assessment of Arctic sea-level rise and resulting coastal hazard impacts, along with a Nunavut Permafrost Monitoring Network and a drinking water supply analysis.
	Northern Strategy Community Adaptation Project[f]	An effort hosted by the Northern Climate ExChange to create and implement adaptation plans for three Yukon communities, starting with Dawson City (completed December 2009), then Whitehorse (ongoing), then Mayo. The project links local stakeholders with experts to develop short-, mid-, and long-term plans (5-20 years, 20-50 years, and 50-100 years). The goal is to 'mainstream' climate adaptation and environmental concerns into local decision-making and daily operations.

Sources: a) Canadian Institute of Planners Web site (ND); personal communication with Philip R. Hill (2010); b) Natural Resources Canada (ND-a), Natural Resources Canada (2010b); c) C-CIARN Coastal Zone website (2007a), C-CIARN Coastal Zone State-of-Play Report 2006-2007 (2007b); d) Environment Canada (ND), Natural Resources Canada (2007c); e) Indian and Northern Affairs Canada (2009); f) Indian and Northern Affairs Canada (2009), Northern Climate ExChange (ND).

Figure 3 (continued): Coastal adaptation initiatives

Geographic Scope	Adaptation Initiative	Description
Local and First Nations	Halifax (NS) Regional Municipality (HRM)[g]	The Halifax Regional Municipality (HRM) has been a leader in climate-change planning, with a planning strategy adopted in 2006 that explicity addressed adaptation. However, a critical information gap on the impact of sea-level rise and storm surges on Halifax Harbour, a major seaport, and other HRM coastal areas was identified while drafting a new Halifax Harbour Plan. An ongoing collaboration has produced flooding estimates with multiple scenarios; adaptation strategies have not yet been developed.
	Delta (BC) Climate Change Initiative[h]	The Corporation of Delta and Tsawwassen First Nations Reserve, on the Fraser River delta lowlands, were studied as part of the NRC/CIP project (see above). The analysis found that the area's 61.5km dike system complicates adaptation, likely exacerbating tidal flat erosion, and that the dikes and port facility causeways may be damaged by the water. In 2009, Delta adopted a multi-tier Climate Change Initiative with a flood management plan that includes upgrades to the seawall, dikes and related infrastructure, as well as a floodplain bylaw to limit development.
	Graham Island (BC) Case Study: Impacts of Sea Level Rise[i]	Northeastern Graham Island, Queen Charlotte Islands (BC), is one of Canada's most sensitive coasts, with high tides and extreme storms that produce erosion of 1 to 3 meters per year. As part of the NRC-CIE municipal case studies (see above), scientists and planning experts worked with local emergency and municipal planners, Haida Nation elders, business owners and residents to gauge vulnerabilities and adaptative capacity. They found local knowledge is crucial to effective adaptation planning, and that remote communities' lifestyles and skills make them unusually resilient to short-term hazards, but they are less prepared for gradual changes such as sea-level rise and accelerating erosion.
	Adaptation to Rising Sea Level in the Bras d'Or Lakes (NS), Canada's Largest Inland Sea[j]	Completed in 2006 by the Geological Survey of Canada, this study projected a water-level rise of 0.36 to 0.76 meters by 2100, with considerable impacts on coastal zones (18.8 percent of coastline was deemed highly sensitive). Three adaptation options were considered – retreat, accommodation, and protection – and the recommended response was to avoid armoring the coast, except to protect crucial infrastructure (highways, bridges, hospitals); to consider cliff retreat patterns in future construction site selection; to avoid developing infrastructure on coastal barriers; and to allow the coast to function as close to the natural state as possible.
	Master Plan for Coping with Shoreline Erosion in Sept-Îles (QC)[k]	The North Shore city of Sept-Îles, which faces urgent marine erosion and land-loss issues along its shoreline and in low-lying coastal plains, is developing a 25-year master plan with recommendations for each of the city's coastal areas, including an intervention scenario that may entail implementing protective measures, or gradually withdrawing and relocating buildings and roads. The plan will be subjected to a cost-benefit analysis and is based on previous coastal erosion analyses, including, most recently, a study by the Ouranos Consortium group.
	Annapolis Royal (NS) Tidal Surge Project[l]	A small coastal community, Annapolis Royal is vulnerable to flooding because much of the land is below sea level. In 1998, a citizens-based group, the Clean Annapolis River Project, launched the Tidal Surge Project, assessing the town's vulnerability to storm surges to identify threats, map out potential flood zones, and develop appropriate responses. Based on the group's findings, several adaptive measures have been taken, including the relocation of much of the fire department's rescue equipment and the purchase of a boat for the department.
	Iqaluit's (NU) Sustainable Subdivision[m]	Iqaluit, capital of the Arctic territory of Nunavut, is developing a 'sustainable' subdivision for up to 370 residential units, to accommodate a rapidly growing population (5,000 as of 2001, up 24 percent from 1996). The project, started in 2003, involved substantial community input as well as partnerships with federal agencies. It involves multiple aspects of sustainability, including adaptation to sea-level rise by building houses on stilts.

Sources: g) Halifax Regional Municipality (2010); h) Natural Resources Canada (2007a), Corporation of Delta (2009); i) Natural Resources Canada (2007b); j) Shaw et al. (2006); k) Mehdi et al. (2006); l) Natural Resources Canada (2010a); m) Mehdi et al. (2006), City of Iqaluit (ND).

Two Approaches to Adaptation

Our review of studies and initiatives related to climate-change adaptation in Canada found two distinct – though often overlapping – approaches. On the ground level, especially in local case studies, there is a focus on direct responses to sea-level rise and increased storm-surge risk, grouped in three categories: retreat (abandoning property, returning the most vulnerable areas to nature), accommodation (zoning restrictions, setbacks, lower-value land uses, elevated construction, flood warning systems), and protection (sea walls, dikes and other barriers, but also nature-focused approaches such as restoring dunes and wetlands that act as natural buffers). On a policy level, meanwhile, the focus has been on building adaptive capacity across the country, with key recommendations such as identifying "best practices" and model policies; ensuring that local decision-makers have continuous access to adaptation expertise and to relevant scientific and technical information; and engaging and educating the public. In addition, several provinces are developing or refining legal frameworks for the protection of coastal areas, to ensure that local authorities have the power and guidance to act.

Direct Responses

The direct responses that have been deemed advisable in different analyses vary considerably by location and circumstances. There is a strong preference for working with nature, rather than against it, to the greatest extent possible (Bras D'Or Lakes, New Brunswick, C-CIARN Coastal Zone projects); there is broad agreement that coastal ecosystems have a substantial intrinsic value, and there is some desire to let nature take its course, as it has for millions of years, shaping and reshaping the coastline without human interference. The latter often also reflects practical considerations: Building on sand or on cliffs might be unwise, because the structures would be too vulnerable to collapse; the same is true of building in areas known to flood during storm surges – certainly if they're not raised above the expected flood level. If a road or bridge has been washed away by previous storms, it may be deemed wise to relocate it, and that might affect access to some coastal properties. In Annapolis Royal, the fire department's rescue equipment was moved from a building that was on a road that is prone to flooding, to a less-exposed site; that was more feasible, local stakeholders agreed, than eliminating the flood risk.

Yet retreat has not been the favored response in most situations – especially not for privately owned land that is already developed or considered usable. Discussions with local stakeholders have repeatedly found that even if they are aware of the risks, people who live and work on the water want to be there and will resist leaving. There is also a cost, which is only escalating as the value of coastal land rises, smaller old houses are replaced by larger ones, and scores of new subdivisions are created (Jordan 2010; New Brunswick Department of Environment and Local Government 2002; Environment Canada 2006). A study of Shediac Bay, in New Brunswick, calculated the cost of vacating all properties with an average flood depth of 1.5 meters or more (Flood Classes 4, 5, and 6) as a result of a storm surge with a 3-meter water level, a total of 42 developed and 52 undeveloped properties: The estimated minimum compensation to the owners of the developed properties was $2.8 million, and for owners of undeveloped properties, close to $560,000. In addition, the study estimated that the province would forgo $50,400 per year in property taxes, and the municipality, $49,700 per year (Environment Canada 2006, Section 4.7).

Protection, meanwhile, is often property owners' first response (Jordan 2010), and some protective barriers have been in place for centuries, used to reclaim land for agriculture and for human settlements (in Annapolis Royal, the first dikes were built by Acadian settlers in the 17th century). Because the land protected by the dikes is often very low-lying and would certainly flood without a barrier, those communities could not survive without the dikes. For example, about half the land area of the Corporation of Delta, in British Columbia, and the adjacent Tsawwassen First Nation reserve, which combined have more than 103,000 residents, is less than 1.5 meters above sea level, whereas high tides can reach 2 meters. The area is protected by a system of nine dikes totaling 61.5km, plus floodboxes, pump stations and inland drainage culverts, and still it often floods in the winter (Corporation of Delta 2009; Natural Resources Canada 2007a). New Brunswick also has extensive diked lands, and in previously unprotected areas, storm damage and concerns about erosion impacts to infrastructure and buildings, including homes, have led to a rapid "hardening" of the coast in the last two decades, with new seawalls, rip-rap mounds and other structures all along the water (Environment Canada 2006).

Yet dikes' and seawalls' ability to protect the land is increasingly in question. The water is going over the dikes and walls, eroding their foundations, and sometimes breaking through (Natural Resources Canada 2007a; Jordan 2010). Delta has budgeted $300,000 to evaluate dike upgrade options and make selected improvements; the option of moving dikes inland has been discussed. The Annapolis Royal assessment recommended raising the local dikes. One New Brunswick review warned that many structures there "will require substantial investment in maintenance, reconstruction or replacement to maintain their protective function" (Environment Canada 2006).

At least equally problematic is the fact that hard barriers often exacerbate the problems they are meant to address. A study of Delta found that while normally, tidal flats and marshland would help dampen the impact of sea-level rise on the Roberts Bank shoreline, with the dikes, the tidal flats are likely to shrink, with more areas submerged and subject to wave attack. (The coastal ecosystems will also be damaged, scientists warned, with stress on the eelgrass habitat, erosion of marshland, and less food for birds and fish.) As the tidal flats erode, the study found, the dikes could be undermined, as well as port and ferry facilities (Natural Resources Canada 2007a).

Some of the strongest arguments against "armoring" the coast were made in the Bras D'Or Lakes study (Shaw et al. 2006), which discouraged the use of hard barriers except to protect essential infrastructure and coastal-zone workers. Armor structures are "often used as the first choice to obtain quick results," the study found, but actually should be a "last resort," because they're expensive[3]; require maintenance; do not promote beach buildup; reduce the supply of sediment from backshore erosion; interfere with natural processes and shoreline response; can promote "wave wrap" around the ends of the structure and erosion of adjacent shores; can squeeze and harm intertidal habitats; interfere with shore access; and are "lifeless" and "can be unsightly."

That said, even the Bras D'Or Lakes study implicitly acknowledges that armoring will continue to happen, so it differentiates between options, noting that rocks (rip-rap) can adjust better to wave processes, whereas more vertical structures such as concrete or timber seawalls are less flexible and also more vulnerable to wave energy. In New Brunswick, the coastal protection policy allows rip-rap, seawalls and bulkheads above the ordinary high-water mark, as long as they follow the contours of the landward limit of coastal lands (beaches, dunes, marshes, etc.), are sloped at no more than 45 degrees, and are built with rocks with "nooks and crannies" to help dissipate wave energy created (New Brunswick Department of Environment and Local Government 2002). Paul Jordan, a sustainable community planner at the New Bedford Department of Environment who oversaw enforcement of the policy for five years, said in an interview (Jordan 2010) that the department warns property owners that even rock walls built to those

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[3] The Shediac Bay study, in New Brunswick, estimates the cost of a seawall at $1,000 per square meter of base surface (Environment Canada 2006).

specifications will lead to increased beach erosion, and it connects them with a coastal geomorphologist who frequently measures and updates coastal erosion rates. Instead of hard barriers, property owners are encouraged to try "soft" options, such as planting dune grass and installing sand fences to trap sand and build up the dunes. "We would prefer if people would use Mother Nature's protection, the beach and the dunes and the wetlands," he said. Still, he acknowledged, most people do not.

Some of the easiest and lower-cost adaptation measures involve accommodation. That is the primary focus of New Brunswick's coastal protection policy as it regards "Zone B," a 30-meter buffer zone between coastal lands and inland areas in which development is tightly regulated.[4] In that zone, no multi-family residences, hotels, apartments or commercial or industrial buildings may be built (except, in the latter two categories, those for which a coastal location is essential). New single-family houses may be built if there are existing structures within 75 meters on both sides of the lot, and existing houses may be expanded by up to 40 percent. To further protect the environment and reduce vulnerability to sea-level rise and storm surges, individuals may not build closer than 10 meters from coastal lands, the habitable portions of new structures must be at least 2 meters above the highest high-water large tide, and water and sewer services must be placed as far as possible from the coastal lands (New Brunswick Department of Environment and Local Government 2002). The policy has been applied to "thousands" of properties often resulting in revised building or development plans, and occasionally stopping projects. Yet the process is not usually adversarial, but rather educational: Many property owners and developers are not aware of the risks they could face, and when they learn about coastal flooding, erosion and other issues, they willingly redesign to account for those factors. There is an appeal process, but Jordan said he knew of only one successful appeal (Jordan 2010).

Delta is preparing a floodplain development bylaw that will take a similar approach, trying to reduce construction below a still-to-be-determined flood level (Corporation of Delta 2009). A more dramatic example of accommodation is the Sustainable Subdivision created in Iqaluit, capital of the Arctic territory of Nunavut. Designed to accommodate 370 residential units, the subdivision adapts to the environment on multiple levels: from building houses on stilts to minimize impact on the topography and reduce flood risks; to sharing driveways to protect the tundra; to aligning roads and buildings in the direction of prevailing winds to minimize snowdrifts and help reduce buildings' heat loss due to wind (Mehdi et al. 2006).

Public-Policy Responses

A crucial point raised again and again in adaptation studies is that because of the diversity of Canada's coastal zones, there is no appropriate "one-size-fits-all" solution. The best approach, both localized and large-scale studies stress, is to combine national- and province-level expertise with the insights of local stakeholders. Local officials and residents seldom have the knowledge of climate science, coastal geology, or adaptation options that experts can provide, the studies note; conversely, without ground-level experience and an understanding of local lifestyles, culture, and other factors, outsiders may not grasp how their recommendations fit with local priorities – and just as important, they may meet with local resistance.

[4] The original policy defined a "Zone C" beyond the 30-meter buffer that would be considered a "transition area" and be subject to special reviews focused on storm-surge susceptibility and ecosystems impacts. After substantial "negative feedback" from the public, however, province officials decided not to enforce the Zone C provisions. However, as the policy is converted to a regulation, with stronger enforcement power, some areas may be designated as subject to the discretion of the provincial minister of environment (2007).

Several projects have successfully bridged this gap: the Municipal Case Studies sponsored by Natural Resources Canada and the Canadian Institute of Planners; the C-CIARN Coastal Zone projects; the Southeastern New Brunswick studies (Environment Canada 2006); the Northern Climate ExChange projects in the Yukon (Indian and Northern Affairs Canada 2009; Northern Climate ExChange ND). Replicating such intensive efforts all across the country seems cost-prohibitive and unfeasible, so broader-based approaches may be needed.

Of particular value here may be the “state-of-play” report (2007b) from the C-CIARN Coastal Zone, a five-year project (2002-2007) that held workshops across Canada on climate change impacts and adaptation and collaborated with local initiatives. It found that while there were many common concerns, priorities varied regionally, and local stakeholders were far more responsive if they perceived a crisis or an acceleration in present-day impacts, or if there was a funding opportunity. Across the board, C-CIARN Coastal Zone also found a desire for more – and more complete – data; for climate scenarios and predictive tools that could be applied locally and regionally; and for methods and tools for adaptation. Making these resources available should be a priority, the report said, and indeed, the government has responded.

Guided by the C-CIARN Coastal Zone insights, and drawing from a $85.9 million government investment, Natural Resources Canada has set up a $30 million Regional Adaptation Collaboratives project and is spending $5 million to develop sharable Tools for Adaptation. The stated goal is to “catalyze coordinated and sustained action” to reduce climate-change vulnerability by advancing adaptation planning and decision-making; these projects are emphatically not research-oriented (Natural Resources Canada ND-d). A total of six Collaboratives are to be funded, for $1 million to $2 million per year, which must be matched by the participants. Eligible entities include non-federal government agencies (provincial, territorial, regional, municipal, and Aboriginal); businesses, industries and professional associations; educational and academic institutions; and nonprofit, non-governmental organizations. Grant-funded projects are only now being announced: British Columbia unveiled its program in late January, and an Atlantic Canada Regional Adaptation Collaborative was announced in April.

The Tools for Adaptation program, led directly by Natural Resources Canada, is geared to developing “decision support tools” such as methodologies and checklists, focused on specific sectors; an example cited is the methodology developed by Engineers Canada to assess the engineering related vulnerability of infrastructure. The tools are to be made available to the Collaboratives and disseminated nationwide.

The Canadian Institute of Planners, meanwhile, which represents 7,000 planners across Canada, has taken on a leadership role in building climate-change and adaptation expertise within the profession. Following its Municipal Case Studies project with Natural Resources Canada, the CIP developed a Climate Change Policy (Canadian Institute of Planners 2009) with three goals: to increase planners’ capacity to mitigate and adapt to climate change; to raise awareness of the links between planning and climate change; and to build networks of professionals to support collaborative solutions to climate-change issues. The CIP has sent planners to communities that lack the expertise to address their own climate concerns, and it is creating educational modules for working planners and related professionals, as well as curriculum units for universities. In October, the CIP is hosting a major climate change conference. Central to all of the CIP’s work is the notion of “mainstreaming” climate-change responses into all aspects of policymaking, a priority also highlighted by NRTEE’s Northern Canada study.

Our research suggests that building national and regional resources should remain a priority and could make a substantial impact, especially if they are widely disseminated and they are tailored to different audiences (a key recommendation of C-CIARN Coastal Zone). However, local-level outreach, education and engagement also remain crucial; the Regional Adaptation Collaboratives may prove to be a particularly effective in this regard, especially if they draw in a wide range of local and regional stakeholders, including government, business, academia and advocacy organizations, as the Atlantic project has done (Natural Resources Canada 2010b).

This still leaves one major obstacle that must be overcome – the absence of effective legal frameworks to support the regulation of coastal zones. There is some irony in this deficiency: British Columbia, which since the 1980s has allowed municipalities and regional districts to protect "environmentally sensitive areas" and "development permit areas," including coastal zones, was once studied as a potential model (see, for example, Jennings and Reganold 1989). Yet key flaws identified in that policy – that it relies on communities' optional adoption of a community plan, and provides no expertise or resources to help local officials address environmental issues – have not, to our knowledge, been addressed yet.

New Brunswick's coastal protection policy offers, in our view, a more workable model – though its impact has also been limited by lack of legal force (the province is now turning the policy into a regulation, a much-stronger status). Currently, provincial authorities can only enforce it on provincial and Crown lands (Jordan 2010), or in provincially funded projects; in municipalities and rural jurisdictions, it serves only as the basis for advisory reports submitted to local authorities (this will change when it becomes a regulation). New Brunswick's experience is instructive here; some communities have carved out conservation zones and limited development in flood- or erosion-prone areas, but many others are loath to be seen as opposing any development, so they "choose to let the province be the bad guy." This, along with the relative scarcity of strong coastal-zone development regulations across the country, suggests to us that at least minimum standards should be set at the province or regional level, with the scientific expertise and resources to back them up.

2d. Study Objectives and Boundaries

The objective of this study is to contribute to a better understanding of the possible economic and welfare implications of the impacts of climate change on Canada's coastal zones, and the role of adaptation in reducing these impacts. More concretely, we will:

- Quantify the potential physical and economic costs of coastal impacts of climate change (e.g. property and land losses from the effects of sea-level rise and more frequent and intense storms) under a range of climate and socioeconomic scenarios, presented in three 30-year time slices centered on 2025, 2055 and 2085.
- Explore the cost-effectiveness of at least two adaptation options in reducing climate-induced coastal impacts.
- Indicate how and where the burden of welfare effects may fall (e.g., by province or territory, socioeconomic grouping, or race/ethnicity).
- Present results in absolute (e.g., 2008 dollars) and relative terms (e.g., percentage of gross domestic product), to allow comparison with the other three studies (human health, public infrastructure, and forest sector) and resonate with stakeholders and the broader public.
- Clearly identify study boundaries, limitations, uncertainties, and assumptions in the analysis.

Figure 4 presents an overview of the boundaries of this study.

Figure 4: Study boundaries

At Risk	Climate Stressors	Climate Impacts Assessed	Geographic Coverage	Time Horizon
Coastal private property	Changes in sea level; changes in storm surge intensity and frequency; erosion	Damage to private property (homes, agricultural property, forest)	All of Canada, disaggregated by province or territory	Three 30-year periods: 2025 (2011-2040), 2055 (2041-2070), and 2085 (2071-2100)
Communities		Displacement from permanent and temporary inundation		
Fresh water resources		Salination of fresh water resources		

Our model estimates damages at the province or territory and national scale due to permanent inundation from sea-level rise and temporary inundation from storm surges for three categories of private assets: dwellings, agricultural land and buildings, and forest land. This is in no way a comprehensive accounting of climate change-related damages. A more complete estimate was limited by the scope of this report and by data availability. Omissions from this analysis include:

- Public infrastructure: Areas inundated in this analysis may include roads, railways, water, sewer, and electricity lines, public buildings, port facilities, power plants, water treatment facilities, etc. (see Environment Canada 2006; McCulloch et al. 2002; Halifax Regional Municipality 2010; NRTEE 2009; Corporation of Delta 2009, among others).[5] Damage to public infrastructure is not considered within the scope of this report.
- Private commercial and industrial property, infrastructure, and operational losses: Inundated areas may also include commercial and industrial properties (e.g. stores, factories, hotels, marinas), but no data exist to estimate the extent or value of private, non-residential infrastructure. Some other studies of sea-level rise damages have employed the following, flawed method: The population that would – in the absence of flooding – have lived in inundated areas is multiplied by five times the projected GDP per capita for those areas; the result is taken as a measure of total assets damaged (see R.J. Nicholls et al. 2007 for a detailed explanation of this method). This broad assumption may be useful in determining the order of magnitude of global results, but – since local and regional GDP per capita is not, in fact, proportional to total asset value – it cannot achieve the detailed results necessary for this study. Business losses due to sea-level rise and storm surges (reduced tourism revenue, the cost of an extended shutdown), meanwhile, may be extensive, but the analysis required to quantify them is beyond the scope of this study.
- Displacement: Human migration – whether local or longer distance – is the necessary result of large-scale inundation. In our model of sea-level rise and storm surges, we assume that when exposed to permanent inundation, properties are abandoned, but when exposed to temporary inundation, properties are rebuilt – even if this inundation occurs repeatedly. Our analysis of adaptation responses focuses on alternative choices that can be made regarding whether to build

[5] See also Stanton and Ackerman (2007) for a GIS-based economic study of the impacts of climate change in Florida that included some analysis of public infrastructure.

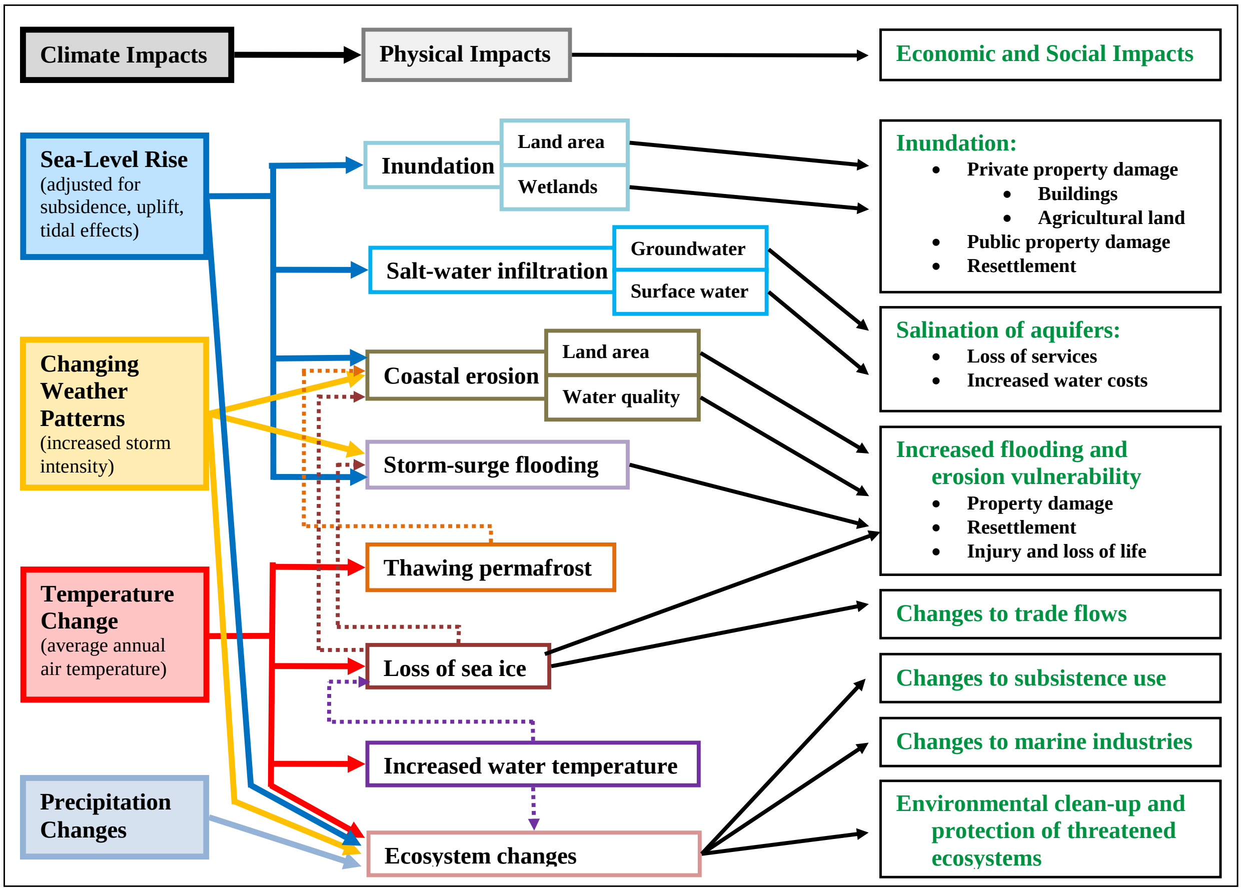
new homes in at-risk areas, and when to abandon properties that sustain repeated damage. Some costs of displacement are captured by our model: When a dwelling is inundated, the damage cost is the value of that dwelling – this cost can be thought of as the price of purchasing another similar dwelling. Other damage costs are extremely difficult to estimate with any confidence and are therefore omitted: A new dwelling may cost more than the value of the damaged home, especially when families are forced to migrate longer distances; migration itself can be costly; it may be difficult to locate employment after moving to another area; and for some communities, migration may separate families from traditional sources of subsistence. Displacement may also have additional immeasurable damages: loss of community, separation for social networks and safety nets; or loss of cultural heritage (Environment Canada 2006; Heberger et al. 2009; Yoskowitz et al. 2009).

- Salination of fresh water: Both surface and underground fresh water can be infiltrated by ocean water as a result of sea-level rise and storm surges. Data exist that allow us to calculate the surface area of above-ground fresh water inundated in our model. We present the results below, but do not attempt to monetize the damages for two reasons. First, it is not possible, within the scope of this study, to translate these surface area results into a volume of water. Second, the process of assigning a value to the damage caused by salination is highly uncertain; impacts on human communities can range from loss of potable water, to health effects from changes in water quality (McMichael et al. 2003), to shortages of water for agricultural uses (Michener et al. 1997).
- Erosion: The most direct effects of sea-level rise and storm surges will be greatly exacerbated by erosion from wave action, changes to sea ice, and changes to precipitation and weather patterns (Nearing et al. 2004; Lemmen et al. 2008, Chapter 4). Erosion not only destroys additional land area, but also results in sedimentation, impacting on water quality and in some cases energy production (Environment Canada 2010). The DIVA sea-level rise impact analysis for Canada uses the "Bruun Rule" to estimate erosion as 100 times the rise in sea-level (i.e. 1 meter of sea-level rise results in an additional 100 meters of inland erosion) (Drozdz 2008), but UNESCO describes this methodology as only appropriate to sandy coastlines (Cambers 1997; for a detailed critique of the Bruun Rule see Cooper and Pilkey 2004, which also documents the lack of satisfactory alternatives).
- Ecosystem effects: The climate impacts to coastal ecosystems are likely to be serious but are outside the scope of this report. A Government of Canada report, *From Impacts to Adaptation* (Lemmen et al. 2008), provides an extensive qualitative overview of these effects of climate change.

SECTION 3: METHODS

Climate change introduces the risk of a wide range of impacts on Canada's coastal zones, as represented in Figure 5. The primary focus of this study is the potential direct damage to private property from the impact of sea-level rise and flooding due to storm surges. The valuation of private property is limited by data availability; in this study economic impacts include damages to homes (including both rented and owned), agricultural land and buildings, and forest land. Distributional impacts are discussed in the concluding section of this report.

Figure 5: Risk assessment



The methodology presented in this section describes our sea-level rise and storm surge flooding model, the purpose of which is 1) to estimate the area permanently inundated and the area at risk of storm surge flooding in each of the climate and socioeconomic scenario pairings discussed in the next sub-section; and 2) to quantify the economic impacts of inundation and flooding in terms of damage to private residential property, agricultural land and buildings, and forests.

3a. Climate Scenarios and Variables

We model three climate scenarios (see Figure 6): *current climate* (no change from present sea levels); *rapid stabilization*, or the SRES B1 scenario, with regional convergence, a shift to more service and information-based economies, less material intensity, and an emphasis on clean and efficient technology;

and *business as usual*, or the SRES A2 scenario, with self-reliant regions, slow growth of per capita income, and slow technological change (Nakicenovic et al. 2000, for detailed descriptions of each scenario, see http://www.ipcc.ch/ipccreports/tar/wg3/081.htm).

Figure 6: Climate and socioeconomic scenarios

			Socioeconomics Scenarios	
		Current Society (baseline projections)	**Local Stewardship** Egalitarians (SRES B2); autonomy: more regional/low grid; community: more environmental/high group	**World Markets** Fatalists (SRES A1FI); interdependence: more global/high grid; consumerism: more economic/low group
Climate Scenarios	**Current Climate** (no change from 2011; relative sea-level rise only)	**CC/CS**	**CC/LS**	**CC/WM**
	Rapid Stabilization (B1) Regional convergence; service/information economy; less material intensity; clean and efficient technology	**B1/CS**	**netB1/LS = B1/LS - CC/LS**	**netB1/WM = B1/WM - CC/WM**
	Business As Usual (A2) Self-reliant regions; slow growth of per capita income and technological change	**A2/CS**	**netA2/LS = A2/LS - CC/LS**	**netA2/WM = A2/WM - CC/WM**

The main climate variable in our model is sea-level rise, although we also look at the impacts of storm surge flooding modeled as the risk-weighted damage from storm surge events (temporary periods of high sea levels). For sea-level rise, we follow the IPCC (2007) central projection for the B1 scenario – 0.28 m in 2100 – and the Rahmstorf (2007) central projection for A2 – 0.85 m in 2100; in both scenarios we assume a linear trend over time.

3b. Socioeconomic Assumptions

We model three socioeconomic scenarios (see Figure 6 above): *current society* (projections to future years but no change from baseline predictions); *local stewardship*, an egalitarian society with a focus on regional autonomy and environmental protection; and *world markets*, a fatalistic society with a focus on regional interdependence and consumerism (NRTEE 2010; Nakicenovic et al. 2000; Dahlstrom and Salmons 2005). The tables below summarize key socioeconomic inputs for each scenario and for each of three 30-year time slices.

Population (Table 1), the number of households (Table 2), GDP (Table 3), and GDP per capita (Table 4) increase over time in all three scenarios. Projections of population and households are higher for the local stewardship scenario than for current society, and higher still for world markets. GDP and GDP per capita are lower for local stewardship than for current society, reaching their highest values in world markets. Visible minorities and the Aboriginal population (Table 5) both grow as a share of total population over time.

Projected agricultural area (Table 6) stays constant in current society, increases over time in local stewardship, and decreases in world markets. Agricultural land and building values (Table 7) differ not by socioeconomic scenario, but by climate scenario, increasing overtime in current climate and increase at a faster rate in B1; in A2, agricultural values increase at a still faster rate until 2080 and then begin to decline. For lack of data, forest area, forest value, and fresh water are set at their base year, current society/current climate rates (Table 8).

Table 1: Projected population

Population	Current Society			Local Stewardship			World Markets		
(thousands)	2025	2055	2085	2025	2055	2085	2025	2055	2085
British Columbia	5,120	6,048	7,104	5,037	5,409	6,374	5,204	6,048	7,104
Manitoba	1,331	1,492	1,684	1,309	1,334	1,511	1,353	1,492	1,684
New Brunswick	801	842	889	788	753	798	814	842	889
Newfoundland	540	531	502	531	475	450	549	531	502
Northwest Territories	48	55	62	47	49	56	49	55	62
Nova Scotia	977	983	972	961	879	872	993	983	972
Nunavut	41	63	84	40	56	75	42	63	84
Ontario	15,193	18,256	21,634	14,944	16,327	19,409	15,442	18,256	21,634
PEI	165	193	223	162	172	200	168	193	223
Quebec	9,161	11,228	13,375	9,011	10,041	11,999	9,311	11,228	13,375
Yukon	38	40	44	37	36	39	39	40	44
Canada	38,639	45,527	53,235	38,006	40,715	47,760	39,273	45,527	53,235

Source: Authors' calculations using National Round Table on the Environment and the Economy (NRTEE) 2010 socioeconomic data.

Table 2: Projected number of households

Households	Current Society			Local Stewardship			World Markets		
(thousands)	2025	2055	2085	2025	2055	2085	2025	2055	2085
British Columbia	2,172	2,581	3,032	2,136	2,308	2,720	2,207	2,581	3,032
Manitoba	564	637	719	555	569	645	574	637	719
New Brunswick	400	429	453	393	384	406	406	429	453
Newfoundland	271	274	259	267	245	232	276	274	259
Northwest Territories	16	18	21	16	16	19	16	18	21
Nova Scotia	455	464	458	447	415	411	462	464	458
Nunavut	14	21	28	13	19	25	14	21	28
Ontario	8,535	10,695	12,674	8,395	9,565	11,370	8,674	10,695	12,674
PEI	74	87	101	72	78	90	75	87	101
Quebec	4,478	5,558	6,621	4,405	4,971	5,940	4,552	5,558	6,621
Yukon	13	13	15	12	12	13	13	13	15
Canada	16,158	19,145	22,386	15,893	17,122	20,084	16,422	19,145	22,386

Source: Authors' calculations using NRTEE 2010 socioeconomic data.

Table 3: Projected GDP

Gross Domestic Product	Current Society			Local Stewardship			World Markets		
(billions CAD2008)	2025	2055	2085	2025	2055	2085	2025	2055	2085
British Columbia	270	489	885	215	312	452	313	760	1,845
Manitoba	57	101	183	56	81	118	82	198	480
New Brunswick	34	60	109	31	46	66	46	111	270
Newfoundland	22	40	72	21	31	45	31	76	184
Nova Scotia	41	72	131	39	57	82	57	138	335
Ontario	823	1,482	2,685	756	1,098	1,594	1,104	2,679	6,504
PEI	6	11	19	5	8	11	8	19	46
Quebec	539	976	1,767	416	604	877	608	1,475	3,580
Canada	2,106	3,792	6,869	1,763	2,559	3,714	2,572	6,244	15,155
Territories	10	18	33	9	14	20	14	33	81

Source: Authors' calculations using NRTEE 2010 socioeconomic data.

Table 4: Projected GDP per capita

GDP per capita	Current Society			Local Stewardship			World Markets		
(CAD2008)	2025	2055	2085	2025	2055	2085	2025	2055	2085
British Columbia	52,305	80,340	123,872	42,499	57,446	70,761	59,470	124,583	257,384
Manitoba	42,536	67,313	108,078	42,543	60,613	77,720	59,728	131,606	283,279
New Brunswick	41,979	71,290	122,118	39,769	60,500	82,840	55,931	131,870	302,465
Newfoundland	41,124	74,965	143,642	40,300	65,725	100,606	56,753	143,798	369,226
Northwest Territories	78,486	114,361	172,134	75,063	96,696	116,170	104,863	209,198	422,424
Nova Scotia	41,607	73,784	135,241	40,529	64,418	94,322	57,104	140,673	345,525
Nunavut	78,486	114,361	172,134	75,063	96,696	116,170	104,863	209,198	422,424
Ontario	53,846	80,721	123,380	50,482	67,061	81,889	70,587	145,373	297,734
PEI	35,572	54,630	85,363	32,879	44,975	56,151	45,984	97,613	204,345
Quebec	58,368	86,357	131,402	46,096	60,027	72,923	64,421	129,972	265,218
Yukon	78,486	114,361	172,134	75,063	96,696	116,170	104,863	209,198	422,424
Canada	54,170	82,849	128,328	46,249	62,670	77,553	64,731	135,935	282,125

Source: Authors' calculations using NRTEE 2010 socioeconomic data.

Table 5: Projected visible minority and Aboriginal population as a share of total population

	Visible Minorities Share			Aboriginal Population Share		
(thousands)	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
British Columbia	0.42	0.49	0.49	0.05	0.05	0.05
Manitoba	0.13	0.15	0.15	0.19	0.20	0.20
New Brunswick	0.04	0.05	0.05	0.03	0.03	0.03
Newfoundland	0.02	0.03	0.03	0.06	0.07	0.07
Northwest Territories	0.08	0.09	0.09	0.62	0.66	0.66
Nova Scotia	0.06	0.07	0.07	0.03	0.04	0.04
Nunavut	0.02	0.02	0.02	0.94	0.98	0.98
Ontario	0.44	0.54	0.54	0.02	0.02	0.02
PEI	0.02	0.03	0.03	0.01	0.02	0.02
Quebec	0.15	0.18	0.18	0.02	0.02	0.02
Yukon	0.05	0.06	0.06	0.29	0.31	0.31
Canada	0.30	0.36	0.36	0.04	0.05	0.05

Source: Authors' calculations using data from PCensus, Statistics Canada (2005a; 2005b).

Table 6: Projected agricultural land area

Agricultural Land Area	Current Society			Local Stewardship			World Markets		
(km^2)	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
British Columbia	8,408	8,408	8,408	8,544	8,828	9,111	8,271	7,987	7,704
Manitoba	61,770	61,770	61,770	62,776	64,858	66,941	60,764	58,682	56,599
New Brunswick	2,154	2,154	2,154	2,189	2,262	2,335	2,119	2,047	1,974
Newfoundland	10	10	10	10	11	11	10	10	9
Northwest Territories	0	0	0	0	0	0	0	0	0
Nova Scotia	1,703	1,703	1,703	1,731	1,788	1,846	1,675	1,618	1,561
Nunavut	2	2	2	2	2	2	2	2	2
Ontario	33,726	33,726	33,726	34,275	35,412	36,549	33,176	32,039	30,903
PEI	2,325	2,325	2,325	2,362	2,441	2,519	2,287	2,208	2,130
Quebec	21,308	21,308	21,308	21,655	22,373	23,091	20,960	20,242	19,524
Yukon	5	5	5	5	5	5	4	4	4
Canada	544,387	544,387	544,387	553,256	571,606	589,956	535,518	517,168	498,817

Source: Authors' calculations using 2005 data from the Commission for Environmental Cooperation of North America's (CEC) North American Environmental Atlas: http://www.cec.org/atlas.

Table 7: Projected agricultural land value

Agricultural Land Value	Current Climate			Rapid Stabilization -- B1			Business-as-Usual -- A2		
(1000 CAD2008 per km^2)	2025	2055	2085	2025	2055	2085	2025	2055	2085
British Columbia	1,259	1,816	2,620	1,344	2,200	3,602	1,355	2,206	2,916
Manitoba	238	343	495	313	759	1,839	325	764	769
New Brunswick	426	615	887	490	923	1,739	499	928	1,112
Newfoundland	660	952	1,373	694	1,104	1,755	698	1,106	1,491
Northwest Territories	429	619	893	494	930	1,754	502	935	1,120
Nova Scotia	464	669	965	497	821	1,355	502	823	1,082
Nunavut	429	619	893	494	930	1,754	502	935	1,120
Ontario	1,413	2,039	2,942	1,597	2,911	5,304	1,621	2,923	3,585
PEI	631	911	1,314	661	1,041	1,641	664	1,043	1,416
Quebec	803	1,158	1,671	917	1,704	3,167	932	1,712	2,071
Yukon	429	619	893	494	930	1,754	502	935	1,120
Canada	429	619	893	494	930	1,754	502	935	1,120

Source: Authors' calculations from Statistics Canada Table 002-0003 ("Value per acre of farm land and buildings, annual (dollars), 1921 to 2008"); Weber and Hauer (2003).

Table 8: Projected forest area, forest value, and fresh water area

	Forest Area	Forest Value	Fresh Water Area
	(1000 km2)	(CAD2008 per km2)	(1000 km2)
British Columbia	645	7,849	22
Manitoba	326	7,849	93
New Brunswick	67	7,849	1
Newfoundland	240	7,849	33
Northwest Territories	450	7,849	164
Nova Scotia	46	7,849	2
Nunavut	12	7,849	208
Ontario	705	7,849	63
PEI	3	7,849	0
Quebec	870	7,849	123
Yukon	215	7,849	8
Canada	4,182	7,849	791

Source: Authors' calculations from 2005 data from the Commission for Environmental Cooperation of North America's (CEC) North American Environmental Atlas: http://www.cec.org/atlas, and Statistics Canada (ND).

We used the following assumptions, in additional to the assumptions provided by NRTEE, in making these projections:

- The number of households is population divided by household size. We assumed a linear trend in household size between data values, and a constant size after 2020. Household size does not vary by socioeconomic scenario.

- From 2011 to 2030, visible minority and Aboriginal populations' shares of total population change at the 2001-to-2017 annual rate projected by Statistics Canada, by province or territory. After 2030, these shares stay constant.[6]
- Agricultural land stays constant in the current society scenario, increases by 10 percent over the period 2011 to 2100 in the local stewardship scenario, and decreases by 10 percent over the period 2011 to 2100 in the world markets scenario.
- Agricultural land and buildings value increases over time following the Canadian historical linear trend from 1976 to 2006; increases over time following the historical trend plus an additional annual trend, by province or territory, for the rapid-stabilization (B1) scenario;[7] and increases over time thorough 2080 following the historical trend plus a larger additional annual trend, by province or territory, for the business-as-usual (A2) scenario, but begins to decrease thereafter.[8] Due to a lack of data, the Northwest Territories, Nunavut, and Yukon were assigned the average Canadian agricultural land value for each year and scenario.
- Forest area does not change over time or by scenario. We have not identified any sources that support additional assumptions.
- The value of forest land does not change over time or by scenario. We calculate this value by dividing the total contribution of forest industries to GDP in 2008 by the total forested land area. We have not identified any sources that support additional assumptions.
- Fresh water does not change over time or by scenario. We have not identified any sources that support additional assumptions.
- All values are converted to CAD2008 using data from Statistics Canada.[9]

In addition to these scenario projections, we assume that spontaneous adaptation will take place in response to current-day sea levels, adjusted for expected relative sea-level rise (unrelated to climate change), and current-day storm surge risk. Only adaptation measures taken in anticipation of or in response to climate change-induced sea-level rise and storm risks *over and above* baseline levels will be considered in our modeling.

3c. Modeling Physical Impacts

Our model of sea-level rise and storm surge flooding examines coastal elevation data to determine what land area would be inundated at each of several meta-scenarios of sea-level rise: a 1-meter, 2-meter, and

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[6] We use the Scenario D projections, which matched the size of these populations – given assumed total population growth – best for 2011.

[7] Weber and Hauer (2003) model the CGMCII scenario, based on IS92a, which is similar to SRES B2, with slightly higher annual average temperatures than SRES B1 (see Barrow 2001; Intergovernmental Panel on Climate Change 2007). The IS92a scenario reaches an increase in global annual average temperatures of 1.2°C in 2051 – the year for which Weber and Hauer model their change in agricultural productivity. We calculated the annual rates necessary to reach these projected values by 2060, the year in which B1 reaches 1.2°C.

[8] Cline (2007) models the change in agricultural productivity in SRES A2 through 2070-2099 and projects a 16-percent increase for all of Canada, as compared to Weber and Hauer's (2003) 65-percent increase by 2051 under a similar scenario. Climate change and agricultural models for the United States (Schlenker et al. 2005; 2006; Deschênes and Greenstone 2007), using increases of 2.8°C (comparable to A2 in 2080) and 8 percent more precipitation by the end of the century, show declining productivity. We calculated the annual rates necessary to reach these projected values by 2045, the year in which A2 reaches 1.2°C. We further assumed that climate change related to agricultural productivity would follow these annual rates until 2080 and then begin to decline at one minus these rates. Several models have used a Ricardian analysis framework to estimate the impact of climate change on agricultural productivity, notably Reinsborough (2003), which projects a negligible increase in productivity through the end of the century. Weber and Hauer attribute Reinsborough's results to a very coarse spatial resolution.

[9] Statistics Canada (2010), http://www40.statcan.ca/l01/cst01/econ46a-eng.htm.

3-meter increase to sea level above today's mean high tide. Elevation data passes through three model stages in order to achieve the final physical results: the land area inundated in each climate scenario for each province or territory. The three model stages are described here in turn: a pre-processing stage using SLR-FIT; a processing stage in ArcGIS; and a post-processing stage in Excel to adjust for relative sea-level rise and to interpolate between meta-scenarios to match the current climate, B1 and A2 climate scenarios in the periods under study (in this model, physical results do not differ by socioeconomic scenario).

SLR-FIT stage

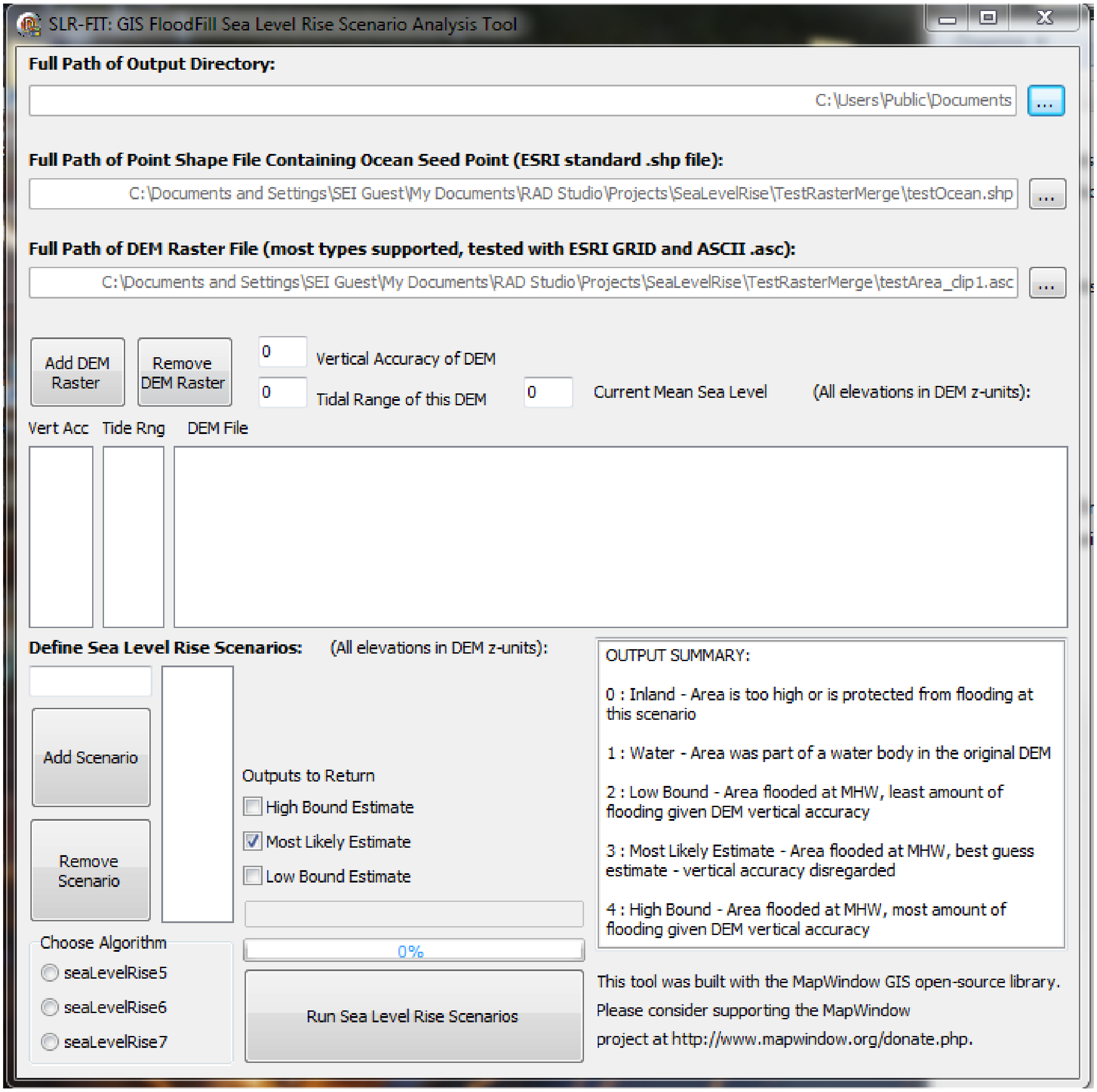
SEI-US's SLR-FIT[10] (see Figure 7) was designed to produce an estimate of the land area inundated by a given rise in sea level. As inputs, SLR-FIT uses an Ocean Seed Point .shp file to indicate where the ocean is in relation to land, digital elevation model (DEM) raster files, mean tidal range for the DEM, current Mean Sea Level (MSL), and sea-level rise scenarios. The .shp file is user generated and specific to the DEM raster (grid-based) files being used. There are two primary DEM raster data inputs. The first is the SRTM[11] raster dataset, with grid cells sized to 250 m^2, and the second is the Commission for Environmental Cooperation's (CEC's) North American Atlas[12] raster dataset grid cells sized to 30 arc-seconds; both datasets have vertical resolution in 1-meter increments, and we make the assumption that the data's mean sea levels are accurate for the present day. Because the SRTM data stops at 60˚N, we use the CEC data for higher latitudes such as the Yukon, Northwest, and Nunavut Territories; northern portions of Quebec, and provinces with coastline along the Hudson Bay.

[10] The SLR-FIT (Sea-Level Rise – Flood-fill Inundation Tool) was developed for several other SEI projects related to mapping inundation and identifying coastal vulnerability to sea level rise. It is still in testing phase, so the beta version has not yet been released publicly.

[11] NASA's Shuttle Radar Topographic Mission (SRTM) provided digital elevation data (DEM) for 80 percent of the globe, through 60 degrees North. The original SRTM 90 m^2 Digital Elevation Data has been re-sampled to 250m^2 and made freely available by the CGIAR Consortium for Spatial Information at http://srtm.csi.cgiar.org. Source: Jarvis, A., H.I. Reuter, A. Nelson, E. Guevara, 2008, Hole-filled SRTM for the globe Version 4, available from the CGIAR-CSI SRTM 90m Database: http://srtm.csi.cgiar.org.

[12] The North American Atlas base elevation layer, available from the CEC, is derived from two sources: 1) GTOPO30 data the U.S. Geological Survey12, and 2) Canada3D elevation dataset produced by the Centre for Topographic Information (Sherbrooke), Natural Resources Canada. Both sources have elevation values regularly spaced at 30 arc-seconds (approximately 1 km^2). According to CEC, Canada3D elevation data is of higher quality and has fewer errors than USGS GTOPO30 data: http://www.cec.org/atlas.

Figure 7: Screenshot of SLR-FIT



SLR-FIT accounts for the appropriate tidal range (the average height of the tide from mean low water to mean high water), allowing us to model the area inundated at mean high tide. Even though tide heights vary annually, their differences are relatively constant in relation to one another – in particular when averaged over at least 18 years, the length of a lunar-tidal cycle. The tidal ranges used in SLR-FIT are representative of each coastal zone (see Table 9). Tidal ranges are assigned on the basis of 38 coastal zones. After surveying the literature regarding Canadian tidal ranges,[13] we followed the advice of the

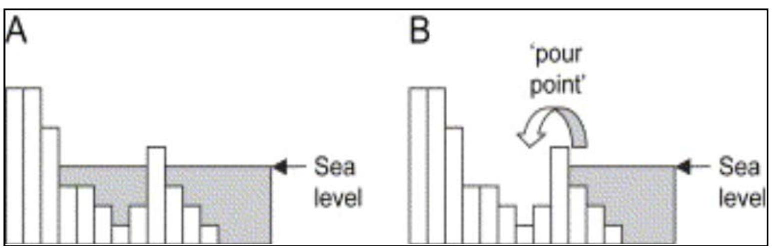
[13] See Gordon (1994); NOAA (ND); The Atlas of Canada (Natural Resources Canada 2010c); NASA (2006); Canadian Hydrographic Service (2010b); Reddy (2001); Cummins and Oey (1997); Cornett (2006); Gagnon (1983); Benke and Cushing (2005); Transport Canada (2009); The Canadian Encyclopedia (2009); Giles (2002); Mann (1972); The Atlas of Canada (Natural

Canadian Hydrographic Service[14] in choosing its *Canadian Tide and Current Tables* (2010a) as our primary source. Additional factors that influence relative sea-level rise (expected future relative sea-level rise) are accounted for in the post-processing model stage.

We reviewed the *Tables* for the entire Canadian coastline and used the following basic methodology to create coastal zones and assign to them the appropriate representative tidal range: Each of the *Tables'* seven volumes is divided into four to ten areas, each with one or more reference ports. Where an area had just one reference port, we assigned its tidal range, rounded to the nearest meter, to the entire area. Where an area had more than one reference port, we looked at the tidal ranges of secondary ports and created coastal zones that fit areas where most of the tidal ranges of the secondary ports rounded to the same whole number (see Table 9).

There are two main ways to spatially model sea-level rise and subsequent coastal inundation: a) a contour-based method that relies solely on elevation data, allowing some low-lying areas to appear inundated despite being surrounded by areas of higher elevation; and b) a flood-fill model that identifies low-elevation "sinks" that only flood when the "pour point" – or the elevation level that water needs to reach before flowing into the sink – is reached (see Figure 8) (Brown 2006). The application of a "flood-fill" technique enforces the requirement that an existing land area can only be flooded if it is adjacent to either the ocean or another flooded area and creates contiguous zones of inundation. We employ the more accurate flood-fill method.

Figure 8: Sea-level rise modeling strategies



Source: Brown (2006).

Resources Canada 2010c); South (1983); NOIA (ND); Hughen et al. (2000); Hannah et al. (2009); Harper (1990); Solomon (2004).

[14] Personal communication with Phillip MacAulay, head of tide currents and water-levels, Canadian Hydrographic Service Atlantic Region, March 24, 2010.

Table 9: Tidal ranges in meters by coastal zone (meters)

No.	Coastal Zone	Province	Model Input
1	Yukon Territory	Yukon Territory	0
2	Northwest Territories	Northwest Territories	0
3	Arctic Archipelago – Mainland Nunavut	Nunavut	1
4	Kugaarut (Pelly Bay)	Nunavut	2
5	Hudson Bay West Shore	Nunavut	3
6	Hudson Bay West Shore	Manitoba	3
7	Hudson Bay West Shore	Ontario	3
8	Sand Head, James Bay	Ontario	2
9	Hudson Bay East Shore	Québec	1
10	Hudson Strait - Ungava Bay	Québec	7
11	Hudson Strait- Iqauit- Cape Dyer	Nunavut	7
12	Nain, Labrador	Newfoundland & Labrador	2
13	Newfoundland & Labrador Atlantic Coast	Newfoundland & Labrador	2
14	St. John's – Trinity Bay	Newfoundland & Labrador	1
15	Argentia – Placentia Bay	Newfoundland & Labrador	2
16	Port aux Basques South Shore	Newfoundland & Labrador	1
17	Harrington Harbor	Québec	1
18	Île d'Anticosti – Mainland Coastline	Québec	2
19	Sept-Îles – Saguenay River	Québec	3
20	Île d'Orléans – Mainland Coastline	Québec	5
21	Port Afred – Québec City	Québec	4
22	Port Grondines – St. Lawrence River	Québec	2
23	Chaleur Bay	New Brunswick	2
24	Northumberland Strait East (Escuminac to Shediac)	New Brunswick	1
25	Abegweit Passage	New Brunswick	2
26	Charlottetown	Prince Edward Island	2
27	Port Rustico – Gulf of St. Lawrence Coast	Prince Edward Island	1
28	Cape Breton	Nova Scotia	1
29	Nova Scotia Atlantic Coast	Nova Scotia	2
30	Bay of Fundy: St. Mary's Bay – Annapolis Basin	Nova Scotia	7
31	Bay of Fundy: Minas Basin	Nova Scotia	10
32	Bay of Fundy: Saint John's Bay	New Brunswick	7
33	Bay of Fundy: Chignecto Bay	New Brunswick	10
34	Alaska – Northern British Columbia	British Columbia	4
35	Outer Coast: Graham Island – Moresby Island	British Columbia	3
36	Inner Coast: Graham Island – Moresby Island – Prince Rupert	British Columbia	5
37	Vancouver – Queen Charlotte Strait – Northern Vancouver Island	British Columbia	3
38	South Vancouver Island	British Columbia	2

Source: Canadian Hydrographic Service (2010a); all ranges rounded to nearest whole number (see methodology description above).

SLR-FIT implements the "flood-fill" technique via an algorithm that considers the elevation value of each cell and then assesses the difference in elevation from its neighbor cells. The stylized grid cells in Figure 9 provide an example; here cells with a 0 value represent the mean sea level. When a 1-meter of sea-level rise is applied to the grid (Figure 9b), SLR-FIT calculates to which of the cell's eight neighbors[15] the water could travel based on their respective elevations; the sea will reach the two cells north of the initial 0 value, as well as four more cells to the southeast. In Figure 9c, with a 2-meter rise, water travels through

[15] North, Northeast, East, Southeast, South, Southwest, West, and Northwest.

the 1-meter and 2-meter cells, and is blocked only by the 3-meter cells “inland” and 4-meter cells on the “coast.”

Figure 9: Sample of flood fill technique

1	1	2	2	2		1	1	2	2	2		1	1	2	2	2
0	2	2	1	3		0	2	2	1	3		0	2	2	1	3
4	0	2	3	3	—	4	0	2	3	3	—	4	0	2	3	3
4	0	1	2	0		4	0	1	2	0		4	0	1	2	0
4	1	2	2	0		4	1	2	2	0		4	1	2	2	0
a. Sample GIS elevation data grid						b. Sample grid, +1m SLR						c. Sample grid, +2m SLR				

Note: Cell values are elevation of mean sea level in meters. Shaded blue areas represent inundation.

Technically, the inundation level (e.g. 1-meter of sea-level rise) must exceed the elevation in order to cause inundation in any grid cell; we have made this modeling choice in order to err on the side of a conservative estimate of inundated land area. In the CEC DEM data used for the higher latitudes, ocean areas are coded as “no data”. According to this data source, lowland coastal areas have an elevation of at least 1 meter; this means that modeling a 1-meter rise in sea-levels results in no land area inundated for areas with no tidal range – Yukon, Northwest Territories, and Nunavut. In order to avoid discontinuities in final results caused by this artifact of the data, for these northern areas we interpolate all results linearly between the 0 and 2-meter meta-scenarios, instead of between 0 and 1, and 1 and 2.

After adjusting for tidal range, SLR-FIT produces an output map that classifies each cell by the sea-level rise meta-scenario at which it would be inundated at high tide.[16] To estimate the land area inundated in a given sea-level rise meta-scenario, we import this output into to ArcView 9.3.1, a geographic information system (GIS) software for visualizing, managing, creating, and analyzing geographic data.[17]

ArcView GIS stage

Because the initial DEM dataset was in a Geographic Coordinate System (GCS) which allows for the elevations to be referenced relative to mean sea level, several data adjustments are necessary in moving from SLR-FIT to ArcGIS. In the raster output produced by SLR-FIT, grid cells are measured in arc-seconds. In a GCS, the degrees of latitude are not consistent in size (they grow smaller as you move further from the Equator and closer to the North or South Pole). In order to estimate the area inundated, the SLR-FIT output must be “transformed” into a Projected Coordinate System measured in meters using ArcGIS (see Figure 10).[18] SLR-FIT also must be adjusted so that the grid cell values – 0 (inland), 1 (water), 2 (flooded area), and 3 (new coastline) – are reclassified as 1 (flooded land), 0 (not flooded land), and “no data” (ocean). This adjustment allows for merging of overlapping zones, as described below.

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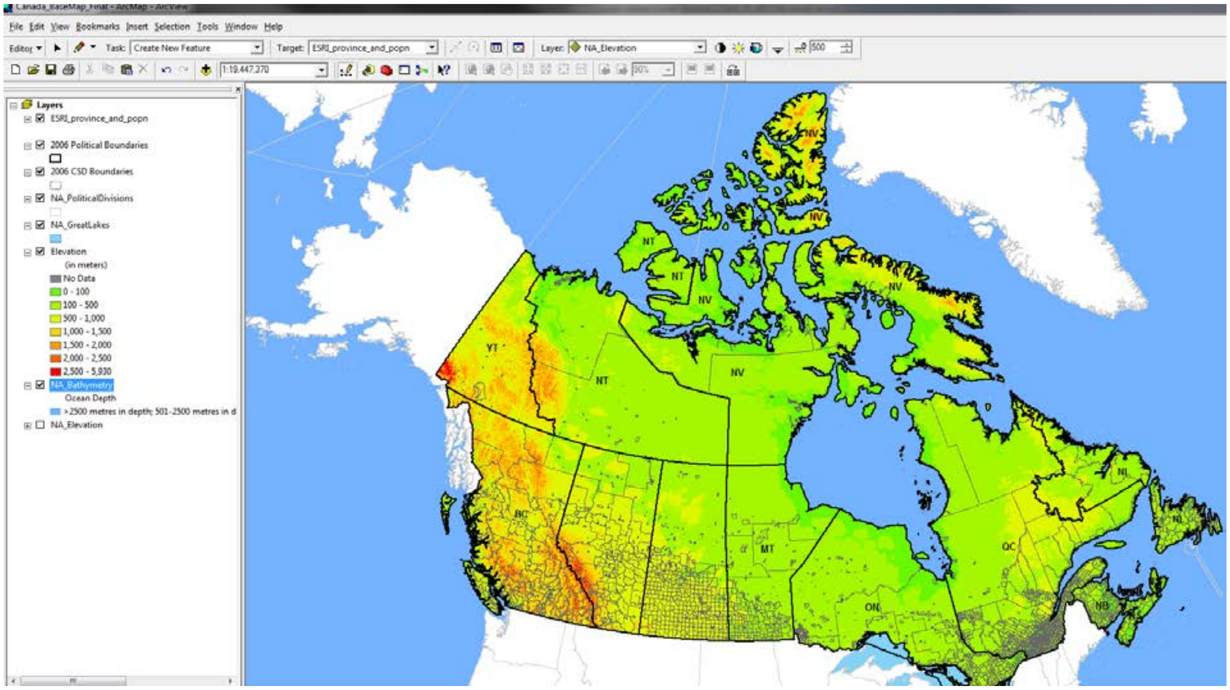
[16] The coastal zones used to assign tidal ranges overlap slightly to avoid any effect of an abrupt boundary on final flooding outputs.

[17] ESRI (2009). For more information, see: http://www.esri.com/software/arcgis/arcview.

[18] Data in Geographic Coordinate Systems (GCS) are defined on a three-dimensional spherical surface. We project raster data from GCS (GCS_WGS_1984, vertical datum: D_WGS_1984) to a projected coordinate system, which is defined on a flat, two-dimensional surface. We use *Canada_Albers_Equal_Area_Conic* (GCS_North_American_1983, vertical datum: D_North_ American_1983, linear unit: meter).

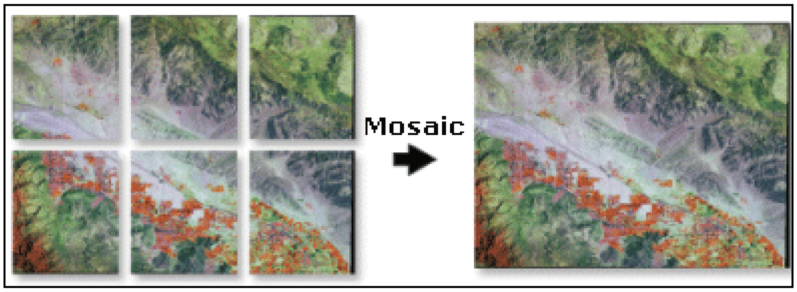
Figure 10: Screenshot of ArcView GIS



Finally, SLR-FIT output includes 38 coastal zones that must be joined together as one map. Each of these coastal zones has been drawn such that it overlaps slightly with its neighbors; this allows the flood-fill analysis to cross these artificial borders. To avoid double counting, the coastal zones are merged (or "mosaiced", see Figure 11) together in ArcGIS where the mosaic function uses an algorithm to compare each set of overlapping grid cells and assign the appropriate value to that cell. The mosaic method chosen depends on the tidal ranges of the overlapping zones. If the zones had the same tidal range, the "maximum" mosaic method was used. This means that if the values for the two versions of a cell are not the same – one is 1 (flooded land) and the other is 0 (not flooded land) – ArcGIS will assign the value 1 to this cell. This mosaic method was chosen to ensure inclusion of contiguously flooded areas across artificial file boundaries.[19]

[19] In a few cases, where small coastal zones are drawn within larger ones in order to account for a strong tidal range variation in one area, we use a mosaic method that prioritizes the result of the small coastal zone over that of it surrounding neighbor. These interior (to another zone) coastal zones are drawn with minimal overlap.

Figure 11: Illustration of the raster mosaic process in ArcGIS

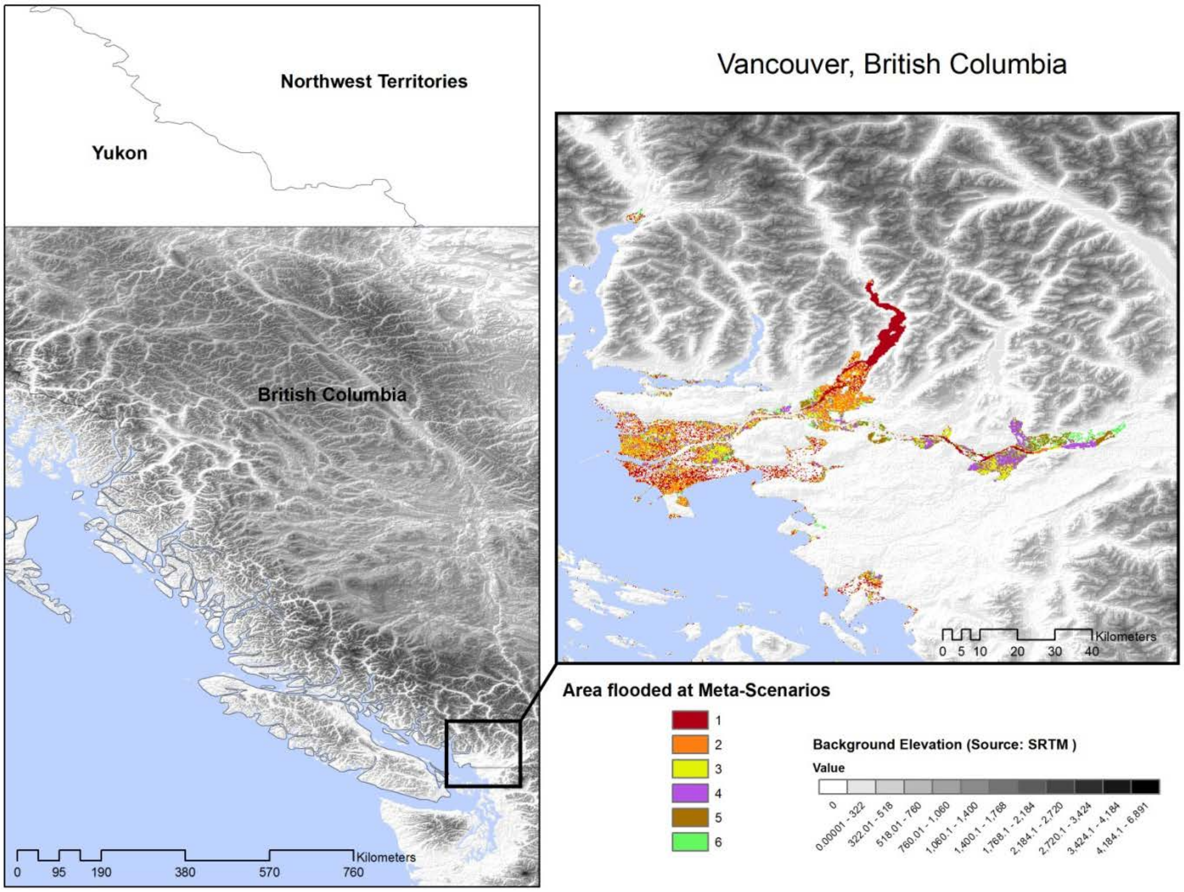


Source: Reproduced from ESRI (2009) Mosaic (Data Management) http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Mosaic_%28Data_Management%29

The transformed, reclassified, and mosaiced results are then processed in ArcGIS to calculate the area inundated by province or territory in each meta-scenario (1-meter rise, 2-meter rise, etc.; see Figure 12); inundated areas do not include present day ocean. Grid cells are then grouped by province or territory, and some provinces and territories are further divided to create sub-province areas with similar relative sea-level rise rates (sub-province regions are discussed more fully in a subsequent section); we refer to these 20 regions as relative sea-level rise (RSLR) areas.[20]

[20] To establish province and territory boundaries we used the CEC (Commission for Environmental Cooperation of North America ND) 2009 Political Boundaries dataset from the *North American Environmental Atlas,* http://www.cec.org/atlas; and the Statistics Canada 2006 Census Boundaries dataset from Tetrad: http://www.tetrad.com/demographics/canada/census/freebdy.html.

Figure 12: Vancouver, British Columbia, inundation map



Once an RSLR area has been mosaiced, we convert the flooded "raster" areas for each meta-scenario into "polygons" using an ArcGIS data conversion tool. We use ArcGIS to calculate the area of each flooded polygon, such that for each meta-scenario, the area inundated by sea-level rise is the sum of the areas of all "flooded" polygons. These polygons also serve as the input into the PCensus software (discussed below), which "reads" boundaries between areas and not the areas themselves.

Excel post-processing stage

The final stage of the physical impact model adjusts the ArcGIS results for expected future sea-level rise, including baseline or relative sea-level rise, and ties the meta-scenario results to the current climate, rapid stabilization, and business-as-usual scenarios. Table 10 reports the relative sea-level rise values that we use as model inputs, along with the data used to arrive at these estimates (note that negative model inputs represent a decline in relative sea-level over time).

Table 10: Relative sea-level rise in millimeters per year

			Koohzare		other sources		Eustatic	Model
No.	RSLR Area	Location	RSLR[a]	VCM[b]	RSLR[d]	VCM	SLR[c]	Input
1	Yukon Territory					-4.0 to -2.0 g	1.1 d	4
2	Victoria Island, NT	Holman			0.85			1
3	Banks Island – Mainland Coastline, NT	Sachs Harbour Tuktoyaktuk			3.6 3.5			4
4	Nunavut	Kugluktuk Resolute			-3.4	5.25 d	1.1 d	-4
5	Manitoba			10.1 to 16.9			1.2 e	-12
6	Ontario			5.4 to 10.1			1.8	-6
7	James Bay – Hudson Bay – Ungava Bay, QC			4.0 to 10.1			1.8	-5
8	North Coast and Labrador, NL			5.4 to 16.9			1.8	-9
9	Atlantic Coast, NL			-4.1 to -2.4			1.8	5
10	St.John's – Trinity Bay, NL	St. Johns	1.93					2
11	Harrington Harbor, NL	Harrington Harbour	0.13					0
12	Île d'Anticosti – Mainland Coastline, QC			2.0 to 5.4			1.7 f	-2
13	St.Lawrence River – Saguenay Fiord, QC	Sept-Îles Baie Comeau Tadoussac St. Francois Quebec St. Jean Port Joli Pointe-au-Père St. Anne des Monts Rivière-au-Renard	0.19 -0.62 -1.21 1.70 1.05 -0.88 -0.31 -0.40 -0.32					0
14	Northumberland Strait, NB	Lower Escuminac Shediac Bay	2.10 2.50					2
15	Prince Edward Island	Charlottetown Rustico	3.30 3.92					4
16	Nova Scotia	Pictou North Sydney Point Tupper Halifax Boutilier's Point Yarmouth	3.70 3.42 3.12 3.27 3.97 4.17					4
17	Bay of Fundy, NB	Saint John	3.01					3
18	Queen Charlotte Strait, BC	Prince Rupert Queen Charlotte City Bella Bella Port Hardy Alert Bay Campbell River	1.04 -0.88 -0.89 -0.65 -1.22 -1.58					-1
19	Strait of Georgia – Juan de Fuca, BC	Point Atkinson Vancouver Stevenson Fulford Harbor Patricia Bay Victoria Sooke Port Renfrew Bamfield	0.80 0.30 1.27 0.24 1.01 0.73 0.82 1.57 0.92					1
20	Outer Vancouver Island, BC	Port Alberni Tofino	-0.37 -1.55					-1

Relative sea-level rise (RSLR) is equivalent to eustatic sea-level rise less vertical crustal movement (VCM).[21]

[21] Koohzare et al. (2008) Table 2 is the primary source for these data. Where data were unavailable from that source, we proceeded to secondary sources in this order: Koohzare et al. (2008) Figure 4; other sources for RSLR; and other sources for

Relative sea-level rise includes eustatic sea-level rise (from oceans' slow expansion unrelated to climate change) and vertical crustal movements (subsidence and uplift).[22] Total projected sea-level rise – climate change-induced together with relative – are reported in Table 11.

Table 11: Total projected sea-level rise (meters)

No.	RSLR Area	Baseline RSLR			Rapid Stabilization (B1)			Business As Usual (A2)		
		2025	2055	2085	2025	2055	2085	2025	2055	2085
1	Yukon Territory	0.08	0.20	0.33	0.13	0.33	0.53	0.23	0.59	0.94
2	Victoria Island, NT	0.02	0.04	0.07	0.07	0.17	0.27	0.17	0.42	0.68
3	Banks Island – Mainland Coastline, NT	0.07	0.18	0.28	0.12	0.30	0.48	0.22	0.56	0.90
4	Nunavut	-0.07	-0.19	-0.30	-0.02	-0.06	-0.10	0.08	0.20	0.31
5	Manitoba	-0.24	-0.61	-0.98	-0.19	-0.48	-0.78	-0.09	-0.23	-0.36
6	Ontario	-0.12	-0.29	-0.47	-0.07	-0.17	-0.27	0.03	0.09	0.14
7	James Bay – Hudson Bay – Ungava Bay, QC	-0.10	-0.26	-0.42	-0.05	-0.13	-0.22	0.05	0.12	0.20
8	North Coast and Labrador, NL	-0.18	-0.46	-0.74	-0.13	-0.34	-0.54	-0.03	-0.08	-0.13
9	Atlantic Coast, NL	0.10	0.25	0.40	0.15	0.38	0.60	0.25	0.63	1.02
10	St.John's – Trinity Bay, NL	0.04	0.10	0.15	0.09	0.22	0.36	0.19	0.48	0.77
11	Harrington Harbor, NL	0.00	0.01	0.01	0.05	0.13	0.21	0.15	0.39	0.62
12	Île d'Anticosti – Mainland Coastline, QC	-0.04	-0.10	-0.16	0.01	0.03	0.04	0.11	0.28	0.46
13	St.Lawrence River – Saguenay Fiord, QC	0.00	0.00	-0.01	0.05	0.12	0.20	0.15	0.38	0.61
14	Northumberland Strait, NB	0.04	0.11	0.18	0.09	0.24	0.39	0.20	0.50	0.80
15	Prince Edward Island	0.07	0.18	0.29	0.12	0.30	0.49	0.22	0.56	0.90
16	Nova Scotia	0.07	0.18	0.29	0.12	0.30	0.49	0.22	0.56	0.90
17	Bay of Fundy, NB	0.06	0.15	0.24	0.11	0.27	0.44	0.21	0.53	0.85
18	Queen Charlotte Strait, BC	-0.01	-0.03	-0.06	0.04	0.09	0.15	0.14	0.35	0.56
19	Strait of Georgia – Juan de Fuca, BC	0.02	0.04	0.07	0.07	0.17	0.27	0.17	0.42	0.68
20	Outer Vancouver Island, BC	-0.02	-0.05	-0.08	0.03	0.08	0.13	0.13	0.33	0.54

Sources: Authors' calculations.

The Excel-based model "looks up" projected sea-level rise values for specific years and climate change scenarios, and returns the land area inundated in each RSLR area by interpolating between the meta-

VCM. Data sources: a) These data are Koohzare et al. (2008) Table 2 final results except where no final result was given; in those cases, the data are Carrera et al. 1991 as cited in Koohzare et al. (2008); b) Koohzare et al. (2008) Figure 2; c) 1.8 mm/yr average global eustatic sea-level rise for the 20th century from Koohzare et al. (2008) is used for all entries without location-specific data; d) Manson et al. (2006); e) Forbes (2000); f) Savard et al. (2008); g) Taylor and Taylor (1997). In addition, we reviewed Drozdz' (2008) discussion of the DIVA sea-level rise model for Canada; the figures that Drozdz reports for DIVA's RSLR inputs appeared, in our view, not to correspond well with the scientific literature, so they were not considered in the calculation of our RSLR model inputs.

[22] Eustatic sea-level rise is based on localized data wherever data were available, and on the global rate elsewhere; see the source notes to Table 10. Vertical crustal movements do not include subsidence from human activities (i.e., the result of water, mineral, oil, or gas extraction).

scenarios' ArcGIS results. Sub-province values are combined to report results for each coastal province or territory. For example, if 0.1 m of sea-level rise were projected in the B1 scenario for the year 2080, then the model would linearly interpolate between the 0-meter and 1-meter meta-scenario results (adjusted for relative sea-level rise) to return the appropriate value. Final results for each time period are the average of the 30-year interval surrounding each period year, 2025, 2055, and 2085.

3d. Modeling Economic Impacts

Economic damages from inundation are estimated by combining the physical model results – inundated area by year and climate scenario – and the socioeconomic and land use data discussed below.

PCensus and land-use data stage

ArcGIS polygon (boundary) files by meta-scenario for each RSLR area are imported into PCensus,[23] which allows us to extract Canada Census (2006) data specific to the inundated zones (see

Figure 13). PCensus aggregates data for all Census units within the inundated boundary. For population and number of dwellings, "block" is the Census' smallest units. For all other variables, the smallest Census unit is the "dissemination area." Where blocks or dissemination areas are intersected by the inundation boundary, PCensus prorates their inclusion in the polygon results based on block-level population or dwellings, as applicable. The outcome is a "Census Profile" for each inundation zone by meta-scenario for each RSLR area (see Figure 14). We use the following variables in our economic and distributional analyses:

- Total population
- Visible minorities
- Aboriginal population
- Number of households
- Average household income
- Number of occupied dwellings
- Average value of dwellings

[23] PCensus for ArcView (Version 9.1.2.1790); PCensus-Canada User's Guide, Version 9.0, July 2009, Tetrad Computer Applications Inc., Ferndale, WA, and Vancouver, BC.

Figure 13: Screenshot of PCensus and polygon file

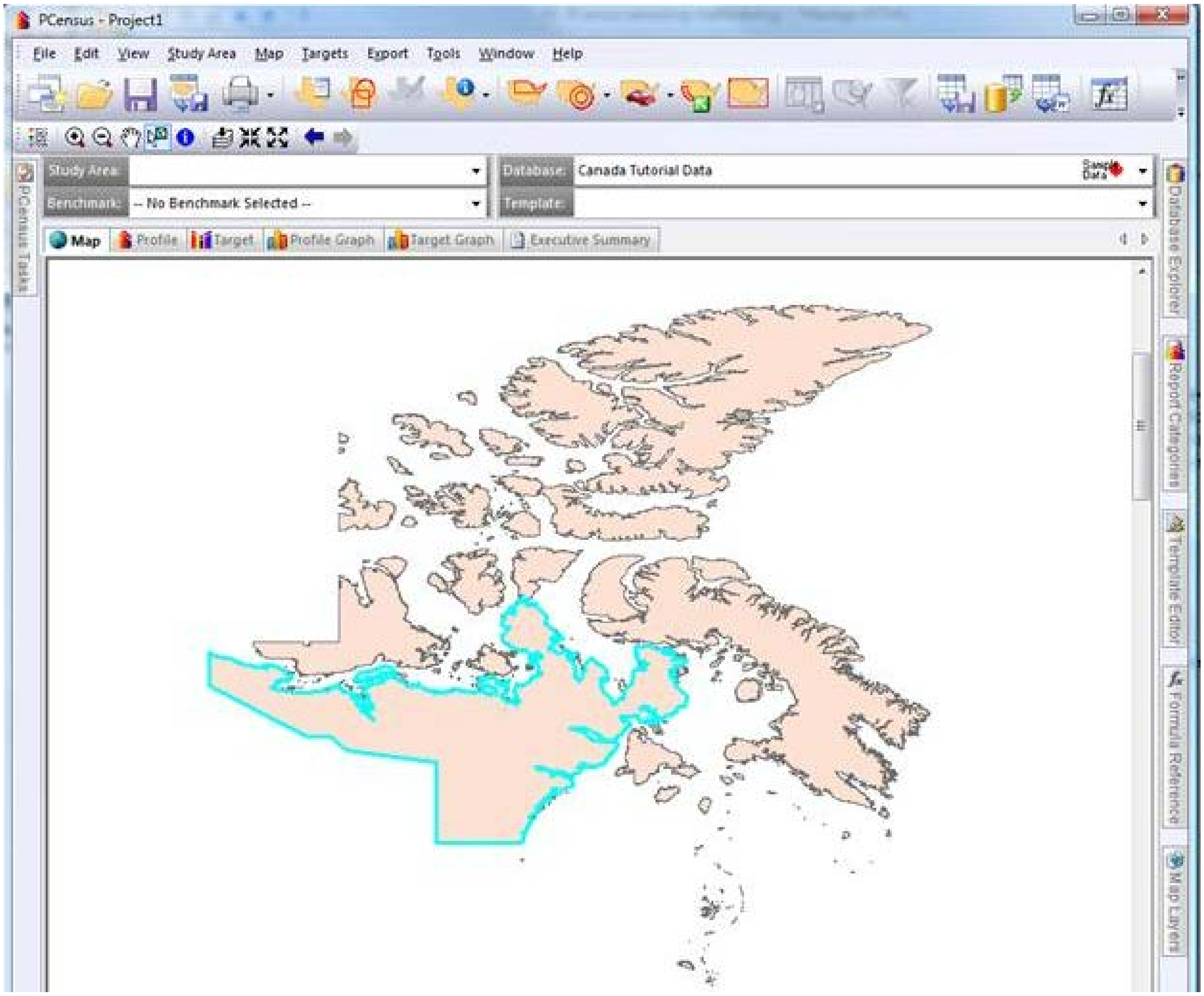
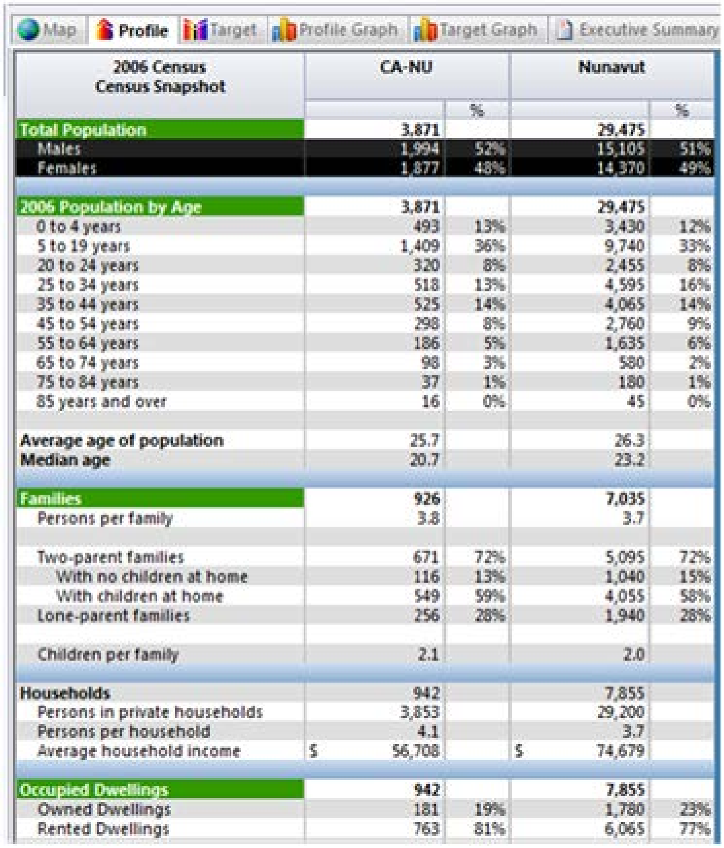


Figure 14: Screenshot of PCensus' Census Profile



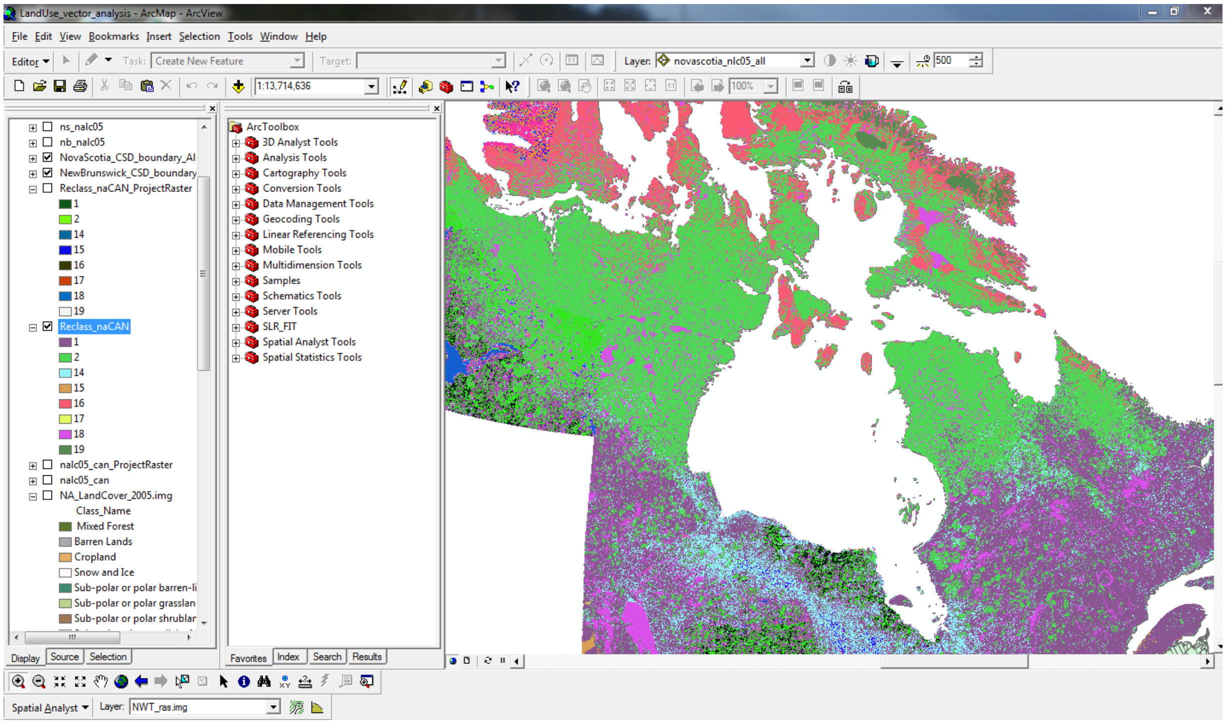
2006 Census Census Snapshot	CA-NU	%	Nunavut	%
Total Population	3,871		29,475	
Males	1,994	52%	15,105	51%
Females	1,877	48%	14,370	49%
2006 Population by Age	3,871		29,475	
0 to 4 years	493	13%	3,430	12%
5 to 19 years	1,409	36%	9,740	33%
20 to 24 years	320	8%	2,455	8%
25 to 34 years	518	13%	4,595	16%
35 to 44 years	525	14%	4,065	14%
45 to 54 years	298	8%	2,760	9%
55 to 64 years	186	5%	1,635	6%
65 to 74 years	98	3%	580	2%
75 to 84 years	37	1%	180	1%
85 years and over	16	0%	45	0%
Average age of population	25.7		26.3	
Median age	20.7		23.2	
Families	926		7,035	
Persons per family	3.8		3.7	
Two-parent families	671	72%	5,095	72%
With no children at home	116	13%	1,040	15%
With children at home	549	59%	4,055	58%
Lone-parent families	256	28%	1,940	28%
Children per family	2.1		2.0	
Households	942		7,855	
Persons in private households	3,853		29,200	
Persons per household	4.1		3.7	
Average household income	$ 56,708		$ 74,679	
Occupied Dwellings	942		7,855	
Owned Dwellings	181	19%	1,780	23%
Rented Dwellings	763	81%	6,065	77%

A similar process is carried out in ArcGIS to extract land use data for these inundated polygons (see Figure 15). Many land-use variables (land cover, developed areas, ecosystem types, infrastructure, surface water) are available as "GIS layers" or data maps. In order to overlay the zone vulnerable to inundation on other GIS data layers, we convert our processed DEM data to a vector polygon data format so that inundated areas are represented as shapes or boundaries instead of individual grid cells – the same process used to prepare boundary files for PCensus. Our land use data is taken from the CEC's North American Environmental Atlas.[24] We use the following variables in our analyses:

- Agricultural lands[25]
- Forested lands[26]
- Fresh water

[24] CEC (Commission for Environmental Cooperation of North America ND) *North American Environmental Atlas*, http://www.cec.org/atlas.
[25] Classified as "cropland" in the CEC *North American Environmental Atlas.*
[26] Classified as "mixed forest," "needleleaf forest," and "deciduous" in the CEC *North American Environmental Atlas.*

Figure 15: Screenshot of land use map layer



Excel modeling stage

Economic impact results are calculated using an Excel-based model to process socioeconomic data imported from PCensus (number of dwellings and their value, demographics) and land use data extracted from map layers using ArcGIS (agricultural land and forested land). The basic structure of the model is described below. Economic damages will include both damage from sea-level-rise-related inundation and risk-weighted inundation from storm surges.

The same methodology is used for all socioeconomic and land use variables. Our model interpolates between meta-analysis results by making the incremental increase to the variable value at the next lowest meta-scenario proportional to the incremental increase in total sea-level (including the regionally specific tidal range and relative sea-level rise) from that same lower meta-scenario. Different sea-level rise values differentiate the current climate, B1, and A2 scenarios. The socioeconomic scenario weighting ratios (the ratio of projected-year to initial-year demographic and land use values for each province or territory) are then multiplied, year by year, with these results to differentiate between the current society, local stewardship, and world market scenarios. (See Appendix A for a more formal description of this model.)

For example, the physical model estimates the land area inundated above current high-tide flooding at 1, 2, and 3 meters of sea-level rise for Prince Edward Island: 50, 105, and 166 km^2, respectively. This land area, expressed as an ArcGIS polygon, is used to extract socioeconomic data from PCensus and land-use data from a CEC map layer. According to this analysis, the number of dwellings in Prince Edward Island inundated at each meta-scenario is 185, 466, and 954. In order to interpolate the correct land area flooded by year and climate scenario, we refer to our calculations of total (relative plus climate-related) sea-level rise. For the year 2050, in the B1 scenario, we project 0.23 meters of total sea-level rise. The total number of dwellings inundated in 2050 in the B1 scenario (before adjusting for socioeconomic scenarios) is 43 (or 185 multiplied by 0.23). Interpolation between meta-scenario results is proportional to total sea-level rise with one caveat: For some RSLR areas and years, total sea-level rise is negative. We do not consider the impacts of declining sea levels in this model.[27] Instead, negative total sea-level rise is modeled as zero sea-level rise.

The next step is to adjust the climate scenario results for our three socioeconomic scenarios. We adjust the number of dwellings based on projections for the number of households (as summarized above). In the local stewardship scenario, there are 113,751 households in 2050, versus 60,000 households in 2011, for a ratio of 1.90. For the world markets scenario, this ratio is 2.09. For Prince Edward Island in 2050, we project 82 dwellings inundated in the B1-local stewardship scenario (43 multiplied by 1.90) and 90 in the B1-world markets scenario (43 multiplied by 2.09).

Damages from sea-level rise are taken to be the value of the annual change in inundated dwellings, agricultural land and buildings, and forests. Dwelling values are the product of the number of dwellings and the average value of dwellings for each climate scenario-socioeconomic scenario pairing. Values assigned to agricultural land and forested land are discussed in Section 3b above.

For storm surges, the modeling is very similar. Here the incremental increase to the variable is net of changes to that variable that result from both climate-change related sea-level rise and relative sea-level rise. Baseline and B1 storm surges are modeled at the severity and frequency values reported in Table 12. A2 storm surge severity is modeled at 110 percent of baseline severity following Dasgupta et al. (2009) and Nicholls et al. (2007).[28] Variables for the areas inundated in storm surges are weighted by the risk of a storm surge occurring (Table 12). Unlike with sea-level rise damages, which are the annual increase to damaged property, storm-surge damages are the full value of dwellings inundated in each year – as if homes were rebuilt after each flood. In model calculations, storm-surge damage frequency is capped at one per year, based on the assumption that rebuilding of homes could happen no more than once per year. Agricultural and forested lands storm-surge damages follow the same logic – as if the owners of this land paid reclamation costs equal to the value of the land after each flooding (where flooding can occur no more than once each year).

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[27] Net negative sea-level rise indicates an increase in land area over time. Because areas currently below sea level are not included as part of the GIS map layers used in this study it is impossible for us to speculate on the extent, topography, or eventual use of lands newly emerged from the sea.

[28] See also Danard et al. (2004) on increased intensity of extra-tropical cyclones as a result of climate change.

Table 12: Baseline storm surge frequency and severity

No.	RSLR Area	AMEG 2006 Severity	AMEG 2006 Frequency	Danard et al. 2003 Severity *meters*	Danard et al. 2003 Frequency *per year*	Model Inputs Severity *meters*	Model Inputs Frequency *per year*
1	Yukon Territory			1.2		1.2	3
2	Victoria Island, NT	low	medium	1.2		1.2	1
3	Banks Island – Mainland Coastline, NT	high	high	1.2		1.2	3
4	Nunavut	low	medium			1.2	1
5	Manitoba					1.2	0.9
6	Ontario	medium	medium			1.2	0.9
7	James Bay – Hudson Bay – Ungava Bay, QC	medium	medium			1.2	0.9
8	North Coast and Labrador, NL	high	medium	1.0 0.8	1.7 1.0	0.9	1.3
9	Atlantic Coast, NL	high	medium	1.0 0.8	0.3 0.8	0.9	0.5
10	St.John's – Trinity Bay, NL	high	medium	0.9	0.1	0.9	0.1
11	Harrington Harbor, NL	medium	medium	1.5 1.1 0.8	1.5 0.3 0.8	1.1	0.9
12	Île d'Anticosti – Mainland Coastline, QC	medium	medium	1.5 1.1	1.5 0.2	1.3	0.8
13	St.Lawrence River – Saguenay Fiord, QC			1.3 0.9 1.3 1.4 1.3 1.5 1.3 1.9 2.0 2.7	0.1 1.0 0.3 0.5 0.1 0.3 0.4 0.2 0.5 0.1	1.6	0.4
14	Northumberland Strait, NB			1.5 1.3 1.3 0.8	1.5 2.0 0.3 2.5	1.2	1.6
15	Prince Edward Island	high	high	1.3 0.9	0.2 2.0	1.1	1.1
16	Nova Scotia	high	medium	0.6 1.1 1.1 1.0 1.1	2.0 0.3 0.1 0.2 0.7	1.0	0.7
17	Bay of Fundy, NB			1.1	0.1	1.1	0.1
18	Queen Charlotte Strait, BC	medium	medium	1.0		1.0	0.9
19	Strait of Georgia – Juan de Fuca, BC	high	medium	1.0		1.0	0.9
20	Outer Vancouver Island, BC	high	medium	1.0		1.0	0.9

Sources: Date sources are Natural Resources Canada (2006) and Danard et al. (2003). Model inputs are taken from Danard et al. where data existed. Where data were absent, we used NRCan 2006 to establish which regions covered in Danard et al. where the most similar in terms of storm surge severity and frequency.

In a final step, variable results by climate scenario, socioeconomic scenario, and time period are aggregated by province or territory, and baseline values for relative sea-level rise only are netted out of the climate-socioeconomic scenario results. It is important to note that all results are also net of the current land area, population, and dwellings that fall below the stylized high-tide line by coastal zone used in the SLR-FIT stage of modeling.[29] Population and dwellings would fall below the high-tide line due to 1) the coarse resolution of spatial data, tidal zones, and relative sea-level rise; or 2) the presence of "hard" coastline protective measures such as dikes and seawalls, which are common in many regions.

Discounting

Economic damages are presented in year 2008 CAD, in two forms: as annual damages, presented as 30-year averages around 2025, 2055, and 2085, and as cumulative damages, using two discount rates to determine the present-day value: 0 percent and 3 percent. (In addition, we present the results of a sensitivity analysis using a 1-percent discount rate in Appendix B to this report.) These results are also reported as a share of Canada's gross domestic product. The 30-year average results are presented as a share of the average GDP in those years; discounted values are presented as a share of projected 2011 GDP.

3e. Rationale of Approach

Our review of the literature of climate change and Canada's coastal zones has shown that the impacts of greatest concern are those related most directly to sea-level rise and storm surge flooding. We begin by estimating the zone at risk of permanent inundation or temporary flooding in a variety of sea-level rise and storm surge flooding scenarios. Our economic analysis focuses on quantifying various characteristics of the inundated zones, as described above.

Adaptation decision criteria

Our analysis of adaptation options focuses on risks and strategies directly connected to sea-level rise and storm surge flooding, but is informed by a broader look at adaptation studies and policies across the country, to identify "best practices," ideas and questions that could be used as models for others. We have used a multi-step process:

Step 1: Set adaptation objectives for each priority risk (threat or opportunity) under investigation:

- Permanent inundation of private property (buildings and agricultural land);
- Increased flooding and erosion vulnerability (private property damage);
- Resettlement, income loss, and loss of subsistence sources of food and fuel;
- Salination of aquifers and surface waters (loss of services; increased water costs).

Step 2: Identify current policies, measures, and structures related to coastal zone and coastal risk management. Our primary sources of information for this step have been government studies, relevant academic and NGO literature, and consultations with sector experts. Decision criteria:

- How effective are these policies and measures in addressing climate variability and extremes?
- How effective are these policies and measures in managing expected relative sea-level rise, if at all?
- What are the knowledge and capacity gaps to be filled in order to more adequately address climate risks?
- How do these policies and measures need to improve to deal with current climatic conditions and future climate change?

[29] Excluding populations and infrastructure below the high-tide mark was artifact of data availability, not a modeling choice.

Step 3: Identify additional policies and measures for adaptation, including both structural and non-structural options. Our primary sources of information for this step have been government studies, relevant academic and NGO literature, and consultations with sector experts. Decision criteria:

- What could be done now to reduce vulnerability and enhance opportunities and adaptive capacity?
- How effective have policies and measures such as these been in other countries?
- How effective are these policies and measures expected to be for Canada?
- How do these policies and measures need to improve to deal with current climatic conditions and future climate change?

Step 4: Qualitative analysis to screen all plausible ("long list") policies and measures for adaptation. Decision criteria:

- What are the main cultural, political, economic, and technical barriers to implementation?
- Are there "win-win," "no-regret," or "low-regret" policies or measures?
- Are there flexible policies or measures that could be implemented at a later date, or implemented separately, in combination, or in sequence?
- Could a policy or measure possibly contribute to climate maladaptation?
- If so, can other options be identified to avoid or limit the maladaptive effect?

The results of this screening process are the "short list" of policies and measures for adaptation. (For a more complete discussion of our analysis, see Section 2c above.) Based on our analysis of the adaptation options for Canada's coastal zone, we selected two adaptation measures for quantitative analysis: curtailing all future construction in the areas for which we project inundation in the A2 scenario by 2100; and gradual abandonment of areas subject to permanent sea-level rise and temporary storm-surge inundation as they become subject to damage. In both cases, adaptation (through the lens of our economic model) results in lower costs: Properties are never developed in flood-prone areas, and properties that are destroyed in floods are not rebuilt. When these measures are implemented, damage costs (loss of coastal property) are greatly reduced. For lack of data, our model cannot calculate the loss of undeveloped coastal real estate or forgone property-tax revenue, but it does calculate the damage to existing dwellings and projected additional future dwellings, and the change to these damages as a result of adaptation measures.

3f. Assumptions, Limitations, and Uncertainties

Our assumptions are laid out in detail in the methodology section above. There are important uncertainties for all of these assumptions, especially relative and climate-change-related sea-level rise, storm surge intensity and frequency, and the discount rate. These key assumptions have been subjected to sensitivity tests, including an interval analysis, for which results are presented in Appendix B.

Here we discuss a few concerns with limitations of the available physical data.

Coarse resolution of elevation data

An anticipated sea-level rise of 1 meter or less is often poorly matched to the available vertical intervals of contour lines found in topographic maps and integer intervals of DEM raster grids.[30] NASA developed sea-level rise scenarios, using their SRTM dataset in collaboration with researchers at the University College of London (UCL). The NASA/UCL inundation analysis was based on corrected 90m SRTM version 3[31] data coupled with the coastlines and water body dataset derived from the NASA SRTM Water Body dataset. The authors write, "given that the typical error in SRTM altitudes is of the order of 3 metres in most coastal areas […] this is a very preliminary analysis intended as a global first assessment and can be much improved by taking on board (a) tides and tidal ranges, (b) better error assessment, (c) improved DEMs in critical areas such as coastal cities" (Mulligan 2007; Mulligan and Stevens 2008).

The elevation data that we use are the best available for all but a few urban or otherwise more extensively studied areas where high-resolution LIDAR studies have been conducted; they are certainly the best data available consistently across the entire Canadian coastline. The precision of the data cannot be determined – it is an uncertain factor in our model; the data may overestimate elevations, underestimate elevations, or some combination of these two errors for different areas of the coastline. A more accurate study of the economic damages of climate change for Canada's coastal zones would require better underlying elevation data, but it cannot be said with any certainty whether this would increase or decrease our estimation of damages, or by how much.

At 243,000 km, Canada's shoreline is the longest in the world. The coastline includes high rocky cliffs; lower cliffs of sand, gravel or mud; sand, cobble or rock beaches; mud flats; marshes; sand dunes, and river deltas.[32] Our assumption of a linear trend in the area inundated between meta-scenarios is a better assumption for coastlines with gradual slopes such as sandy beaches and mudflats than it is for cliffs. (This is to say nothing of the challenge of interpolating flooded areas of coastal zones where coastlines are delineated by seasonal sea ice. Arctic coastal ecosystems behave as non-linear systems, with feedback processes such as erosion, which could increase exponentially as sea-level rises or sea ice disappears.) A national assumption regarding linear trends of flooded areas could lead to an overestimation of land inundated in a given scenario. Overstating the extent of inundation could be perceived as alarmist, while an underestimation could contribute to maladaptation.

Vertical data resolution issues

Mean sea level is used as the reference surface for topographic elevations such as the data employed in this study. Accurately mapping areas potentially inundated by rising seas depends on correct measurements of current mean sea level as well as high-resolution terrain data to position in relation to mean sea level. The uneven distribution of mass across the planet makes it tricky to measure relative sea level.

The geoid is the level surface of that the sea surface would assume in the absence of external gravitational forcing. Sea level approximates the geoid in most areas, and as the geoid migrates depending on various geo-physiological changes in the earth's core, the level of the sea must migrate similarly (Figure 16).

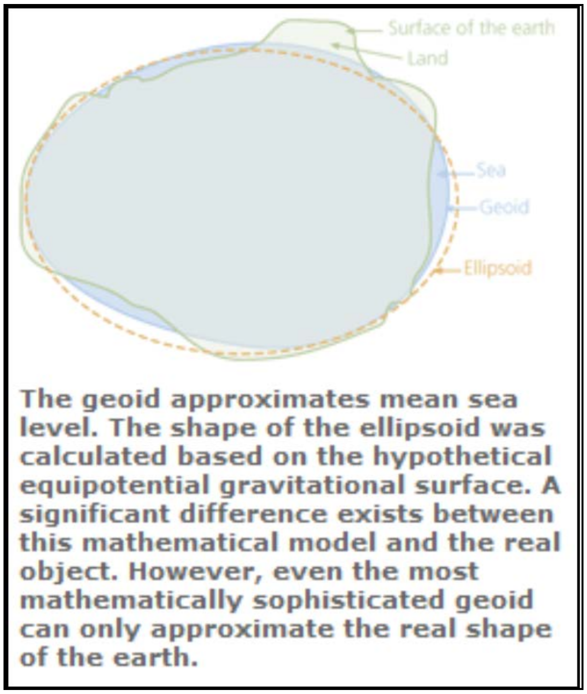
---

[30] Titus, J.G., and C. Richman (2001). "Maps of lands vulnerable to sea level rise: Modeled elevations along the US Atlantic and Gulf coasts." *Climate Research* 18: 205-228; CARA (2006) "Mapping Sea-Level Rise," CARA website: http://www.cara.psu.edu/about/mappingsealevelrise.asp.

[31] Each new version of the SRTM data reflects a processing of the data, usually to correct errors and fill holes.

[32] NRCan CoastWeb, *Geological Survey of Canada* website (2007) http://gsc.nrcan.gc.ca/coast/facts_e.php.

Figure 16: Model of the Earth, approximating sea level and geoid



Source: Fraczek (2003).

Most maps and mapping systems like ArcGIS, however, use a reference ellipsoid, which is an idealized, smoother rendition of the earth's surface that may suggest misleading mean sea levels on which sea-level rise scenarios are layered (Fraczek 2003). The mean ocean surface has slight hills and valleys similar to land topography, but much smoother. Globally, these hills and valleys range from -2.0 m to +2.0 m. Because several coastal applications (i.e. beach nourishment plans, built infrastructure siting, and mapping sea-level rise) require relating elevations with respect to mean sea level, it is important to determine the difference between the geoid and mean sea level. In Canada, the Canadian Geodetic Vertical Datum 1928 (CGVD28) is considered orthometric zero (Natural Resources Canada ND-c). A recent study in New Brunswick – an area known to be experiencing considerable subsidence – using LiDAR-based DEM, however, found that point was actually about 20 cm below mean water level as determined at the Pointe-du-Chêne tide gauge, indicating a shift from orthometric zero (Environment Canada 2006). (Note that the tidal range data used in our model have the same limitation: Their baseline may not be perfectly equivalent to orthometric zero (Environment Canada 2006)).

In our analysis, we assume that across Canada, the 0-meter elevation in our datasets is orthometric zero and mean sea level. We mention the New Brunswick study here merely to illustrate the shortcomings of this assumption. Correcting for local vertical land movements and local eustatic changes would require site-specific investigations using higher-resolution elevation data, preferably LiDAR, a level of technical detail that would be prohibitively expensive and therefore is outside the scope of this study. Instead, we correct for vertical land movements and eustatic sea level changes at a provincial or territorial and sub-provincial scale.

Table 13 presents a summary of the reliability of our analysis according to physical impacts, economic valuation, and adaptation valuation. In general terms, we are confident in our projections, given currently available data.

Table 13: Summary of Impacts

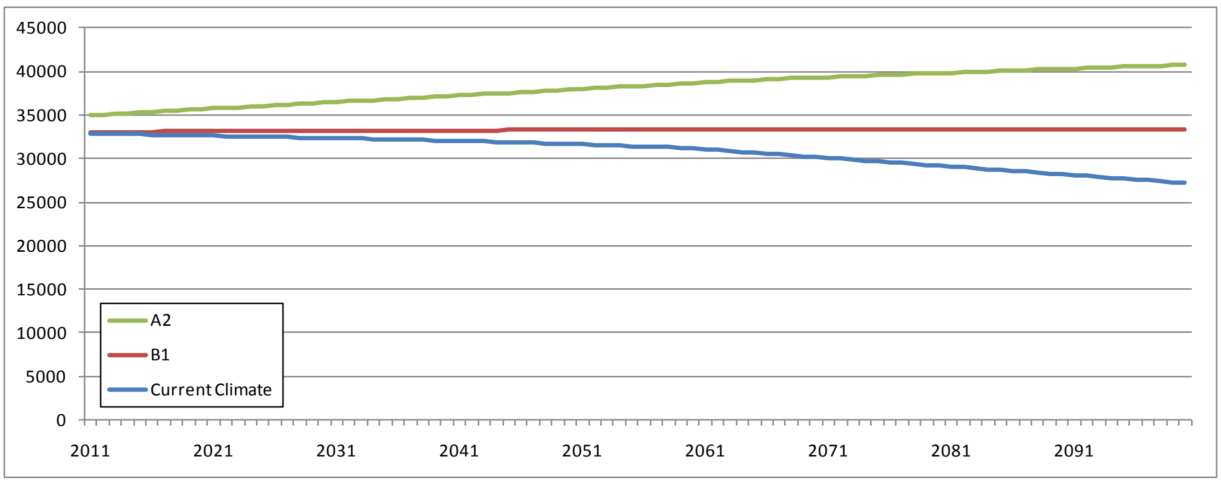
	Specific Impact Quantified	Proxy for Welfare Change	Geographic Coverage	Confidence in Overall Assessment
Physical impact quantification	Land area inundated	N/A	All Canada by province or territory	B
Economic valuation:				
Dwellings damaged or destroyed	Value of homes flooded	Number of dwellings multiplied by average value of dwellings	All Canada by province or territory	B
Agricultural land and buildings damaged or destroyed	Value of agricultural land and buildings flooded	Agricultural land area multiplied by value of agricultural land and buildings	All Canada by province or territory	C
Forest land damaged or destroyed	Value of forest land flooded	Forest land area multiplied by value of forest land	All Canada by province or territory	C
Adaptation valuation	Value of homes not built or rebuilt in inundated areas	Number of dwellings multiplied by average value of dwellings	All Canada by province or territory	B

Confidence: A = Very confident; B = Confident, reliable; C = Plausible, not very reliable; D = Low conficence, unreliable; and E = Very low confidence, very unreliable. Confidences relates to overall assessment, including impact quantification and valuation.

SECTION 4: ESTIMATES OF PHYSICAL IMPACTS

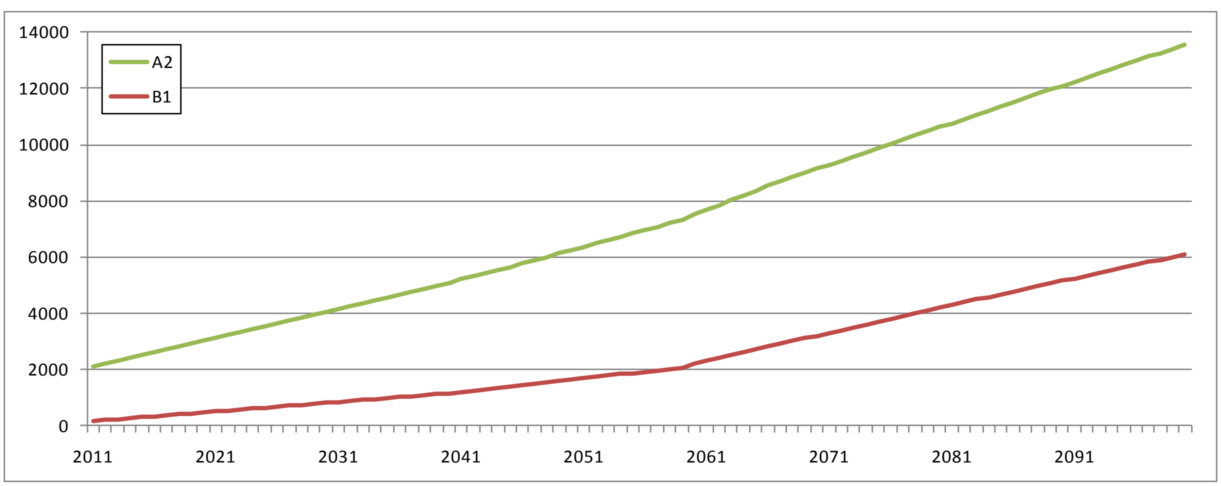
The land area exposed to inundation reported in Figure 17 and Table 14 results from the combination of relative sea-level rise, climate change-related sea-level rise, and storm surge height. Figure 18 and Table 15 report the land area exposed to inundation by climate change net of baseline relative sea-level rise. While economic damages from sea-level rise are presented as additional annual damage, here the land area exposed is the total land area inundated up to the indicated year (where summary results are averages across 30-year time slices). The land exposed to storm surge is over and above total sea-level rise in a given year and is not weighted by the risk of these events' occurrence. The total land area exposed to inundation (including relative sea-level rise) increases over time under the A2 scenario, but, because of significant negative relative sea-level rise in many coastal areas, decreases under B1 and the current climate. The land area exposed to inundation by climate change alone reaches 6,000 km^2 (6/100^{ths} of a 1 percent of Canada's total land area) under B1 and 14,000 km^2 (14/100^{ths} of 1 percent) under A2.

Figure 17: Total land area exposed to inundation (km²)



Source: Authors' calculations.

Figure 18: Land area exposed to inundation by climate change (km²)



Source: Authors' calculations.

Table 14: Total land area exposed to inundation (km²)

	Current Climate			Rapid Stabilization (B1)			Business As Usual (A2)		
Province	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
British Columbia									
SLR exposure	2	6	10	13	33	54	37	95	152
Storm surge exposure	238	235	233	236	231	226	244	228	211
Total	**240**	**242**	**243**	**249**	**264**	**280**	**282**	**322**	**363**
Manitoba									
SLR exposure	0	0	0	0	0	0	0	0	0
Storm surge exposure	476	294	110	499	356	211	598	538	475
Total	**476**	**294**	**110**	**499**	**356**	**211**	**598**	**538**	**475**
New Brunswick									
SLR exposure	10	26	41	20	50	80	39	100	161
Storm surge exposure	232	235	238	234	239	244	263	273	282
Total	**242**	**261**	**279**	**254**	**289**	**325**	**303**	**373**	**443**
Newfoundland and Labrador									
SLR exposure	3	8	13	5	13	20	9	22	37
Storm surge exposure	157	111	65	166	134	102	205	201	199
Total	**160**	**119**	**78**	**171**	**147**	**123**	**213**	**224**	**236**
Northwest Territories									
SLR exposure	230	585	939	407	1,033	1,660	767	1,947	3,127
Storm surge exposure	4,273	4,273	4,273	4,273	4,273	4,273	4,700	4,693	4,255
Total	**4,503**	**4,857**	**5,212**	**4,680**	**5,306**	**5,932**	**5,467**	**6,640**	**7,382**
Nova Scotia									
SLR exposure	7	19	30	13	32	52	23	59	96
Storm surge exposure	106	111	115	108	116	124	127	141	155
Total	**113**	**129**	**145**	**121**	**148**	**175**	**150**	**201**	**251**
Nunavut									
SLR exposure	0	0	0	0	0	0	1,549	3,932	6,316
Storm surge exposure	20,848	20,060	18,088	21,142	20,923	20,705	20,901	19,219	17,538
Total	**20,848**	**20,060**	**18,088**	**21,142**	**20,923**	**20,705**	**22,450**	**23,152**	**23,853**
Ontario									
SLR exposure	0	0	0	0	0	0	94	239	385
Storm surge exposure	2,834	2,465	1,979	2,900	2,761	2,530	3,100	3,026	2,951
Total	**2,834**	**2,465**	**1,979**	**2,900**	**2,761**	**2,530**	**3,194**	**3,265**	**3,336**
Prince Edward Island									
SLR exposure	4	9	14	6	15	24	11	28	45
Storm surge exposure	56	56	57	56	57	58	63	64	67
Total	**59**	**65**	**71**	**62**	**72**	**82**	**74**	**92**	**112**
Quebec									
SLR exposure	0	0	0	6	15	24	138	351	564
Storm surge exposure	2,776	2,543	2,157	2,822	2,757	2,662	2,927	2,813	2,686
Total	**2,776**	**2,543**	**2,157**	**2,828**	**2,772**	**2,687**	**3,066**	**3,164**	**3,250**
Yukon Territory									
SLR exposure	14	36	58	23	59	94	41	105	168
Storm surge exposure	214	214	214	214	214	214	236	234	199
Total	**228**	**250**	**272**	**237**	**273**	**309**	**277**	**339**	**367**
Canada Total									
SLR exposure	271	689	1,106	493	1,251	2,009	2,710	6,879	11,049
Storm surge exposure	32,209	30,596	27,528	32,650	32,062	31,349	33,363	31,431	29,019
Total	**32,480**	**31,285**	**28,635**	**33,142**	**33,313**	**33,358**	**36,073**	**38,309**	**40,067**

Source: Authors' calculations.

Table 15: Land area exposed to inundation by climate change (km²)

Province	Rapid Stabilization (B1) 2025	Rapid Stabilization (B1) 2055	Rapid Stabilization (B1) 2085	Business As Usual (A2) 2025	Business As Usual (A2) 2055	Business As Usual (A2) 2085
British Columbia						
SLR exposure	11	27	43	35	88	142
Storm surge exposure	-2	-4	-7	7	-7	-22
Total	**9**	**23**	**36**	**42**	**81**	**120**
Manitoba						
SLR exposure	0	0	0	0	0	0
Storm surge exposure	24	63	101	123	244	365
Total	**24**	**63**	**101**	**123**	**244**	**365**
New Brunswick						
SLR exposure	10	25	39	29	75	120
Storm surge exposure	2	4	6	31	38	44
Total	**11**	**28**	**46**	**60**	**113**	**164**
Newfoundland and Labrador						
SLR exposure	2	5	8	6	14	24
Storm surge exposure	9	23	37	47	90	134
Total	**11**	**28**	**45**	**53**	**105**	**158**
Northwest Territories						
SLR exposure	177	449	721	537	1,362	2,187
Storm surge exposure	0	0	0	427	421	-17
Total	**177**	**449**	**721**	**964**	**1,782**	**2,170**
Nova Scotia						
SLR exposure	5	13	21	16	41	65
Storm surge exposure	2	5	8	21	31	40
Total	**7**	**19**	**30**	**37**	**71**	**106**
Nunavut						
SLR exposure	0	0	0	1,549	3,932	6,316
Storm surge exposure	294	864	2,617	53	-840	-550
Total	**294**	**864**	**2,617**	**1,602**	**3,092**	**5,765**
Ontario						
SLR exposure	0	0	0	94	239	385
Storm surge exposure	66	297	551	266	561	973
Total	**66**	**297**	**551**	**360**	**800**	**1,357**
Prince Edward Island						
SLR exposure	2	6	10	8	19	31
Storm surge exposure	0	1	1	7	8	10
Total	**3**	**7**	**11**	**14**	**27**	**41**
Quebec						
SLR exposure	6	15	24	138	351	564
Storm surge exposure	46	214	505	151	270	529
Total	**52**	**230**	**530**	**290**	**621**	**1,093**
Yukon Territory						
SLR exposure	9	22	36	27	68	110
Storm surge exposure	0	0	0	21	20	-15
Total	**9**	**22**	**36**	**48**	**88**	**95**
Canada Total						
SLR exposure	221	562	903	2,438	6,190	9,942
Storm surge exposure	441	1,466	3,820	1,154	835	1,490
Total	**662**	**2,029**	**4,723**	**3,593**	**7,025**	**11,433**

Source: Authors' calculations.

The land area exposed to inundation declines over time in some provinces due to two factors. First, negative relative sea-level rise is larger than the B1 sea-level rise rate for coastal Manitoba, Nunavut, Ontario, and parts of Quebec and Newfoundland and Labrador. Even in the A2 climate scenario, relative sea-level rise cancels out climate-related sea-level rise in coastal Labrador, the north coast of Newfoundland, and Nunavut. In these areas and scenarios, sea level is falling, not rising. Second, even when total (relative plus climate-induced) sea-level rise is positive, it is possible for the additional area inundated by storm surges to decline over time under very specific topographic conditions, especially if the total sea-level rise rate is relatively slow (see British Columbia and Northwest Territories under B1 and A2, and Manitoba, Ontario, and Quebec under A2). The topography that causes this effect is characterized by a very gradually sloped coastline, with steeper slopes not far inland. Under these conditions, early increases to sea level have a much bigger impact on the land area inundated than do later increases. (Imagine the first meter of sea-level rise flooding a wide beach, but the second meter flooding very little land because the coastline has reached a cliff.)

When land inundated in storm surges – the additional land inundated over and above sea-level rise inundation – is smaller in one or both of the climate-change scenarios than in the current-climate scenario for some provinces or territories, the result is net negative land inundated. Again, the reason is topography. The storm surge under climate change takes place on a different section of the shoreline (in our example above, the cliff) than the current-climate storm surge (the gently sloped beach). The total area inundated, however, is still greater for every single province and territory in the B1 and A2 climate scenarios than with the current climate.

SECTION 5: ESTIMATES OF ECONOMIC IMPACTS

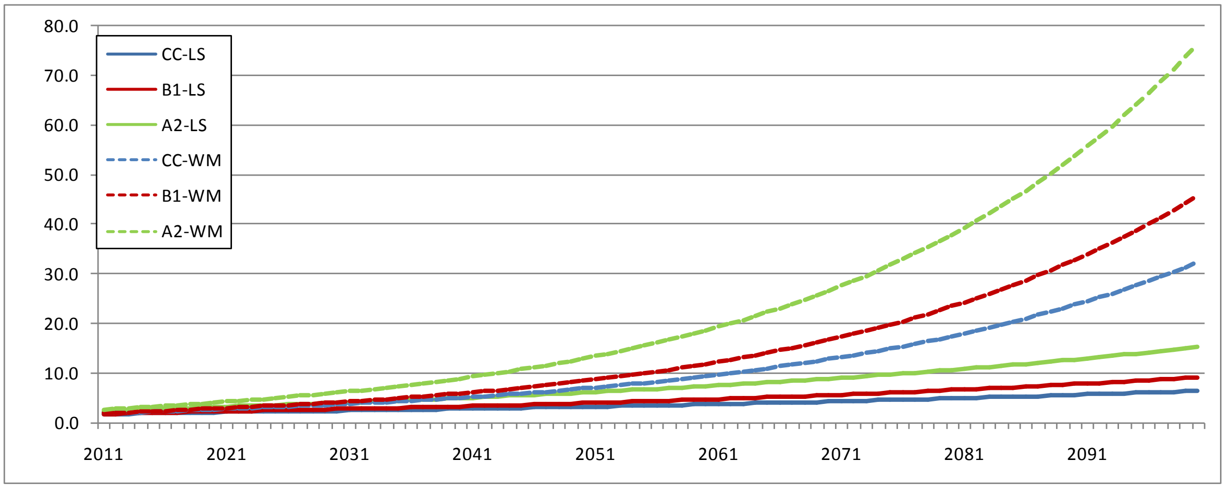
Annual economic damages to Canada's coastal areas from sea-level rise and storm surge inundation range from 0.4 to 3.0 percent of GDP (where each year's damages are compared to that same year's GDP) in the 2080s (Table 16). Climate-induced damages alone (net of damages in the baseline current climate-local stewardship or current climate-world markets scenario) range from 0.1 to 1.6 percent of GDP (Figure 19 and Figure 20).

Table 16: Annual economic damages, absolute (billions CAD2008) and GDP share

Total Damages	2025	2055	2085
CC-LS	2.3	3.5	5.4
CC-WM	3.3	8.5	21.5
B1-LS	2.6	4.4	7.3
B1-WM	3.7	10.6	29.4
A2-LS	3.7	6.9	11.9
A2-WM	5.4	16.6	48.1
Net B1-LS	0.3	0.9	2.0
Net B1-WM	0.4	2.1	7.9
Net A2-LS	1.4	3.3	6.6
Net A2-WM	2.0	8.1	26.6
Damages as a share of each year's GDP			
CC-LS	0.2%	0.2%	0.4%
CC-WM	0.2%	0.5%	1.3%
B1-LS	0.2%	0.3%	0.5%
B1-WM	0.2%	0.7%	1.8%
A2-LS	0.3%	0.5%	0.8%
A2-WM	0.3%	1.0%	3.0%
Net B1-LS	0.0%	0.1%	0.1%
Net B1-WM	0.0%	0.1%	0.5%
Net A2-LS	0.1%	0.2%	0.4%
Net A2-WM	0.1%	0.5%	1.6%

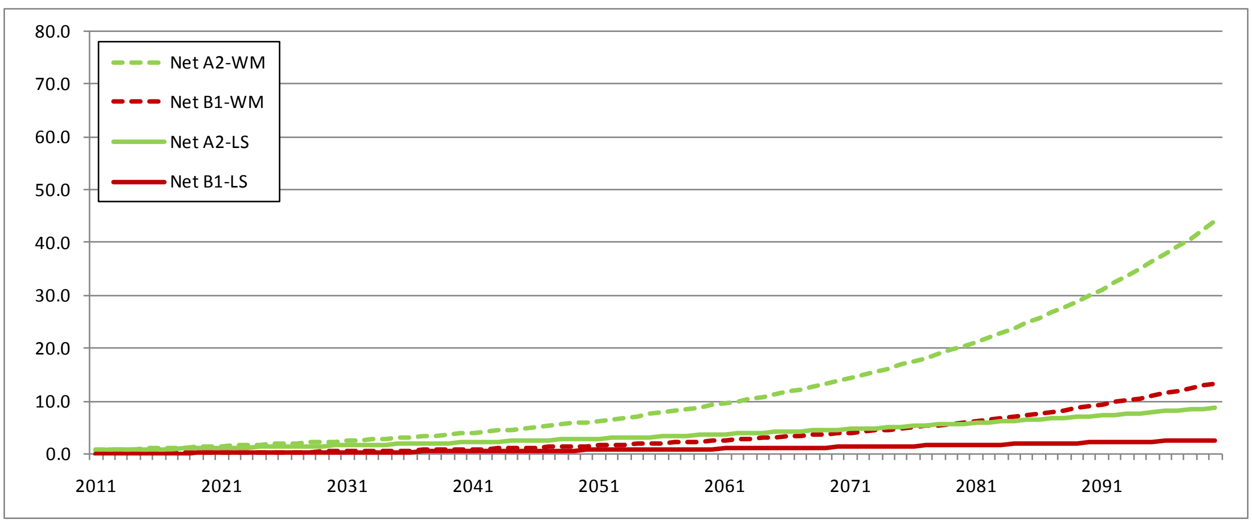
Sources: Authors' calculations.

Figure 19: Annual economic damages from inundation (billions CAD2008)



Sources: Authors' calculations.

Figure 20: Annual economic damages from climate-induced inundation (billions CAD2008)



Sources: Authors' calculations.

Table 17: Cumulative economic damages from inundation, absolute (billions CAD2008) and GDP share

	CC-LS	CC-WM	B1-LS	B1-WM	A2-LS	A2-WM
Absolute damages						
Discount Rate						
3 percent	91.7	197.4	109.3	244.9	165.2	379.6
0 percent	336.8	999.0	429.4	1,313.3	675.8	2,103.4
Damage as a share of 2011 GDP						
Discount Rate						
3 percent	6.3%	12.2%	7.5%	15.1%	11.3%	23.4%
0 percent	23.0%	61.6%	29.3%	81.0%	46.2%	129.7%
2011 GDP	1,463.6	1,622.1	1,463.6	1,622.1	1,463.6	1,622.1

	Net B1-LS	Net B1-WM	Net A2-LS	Net A2-WM
Absolute damages				
Discount Rate				
3 percent	17.6	47.5	73.5	182.2
0 percent	92.6	314.3	339.0	1,104.5
Damage as a share of 2011 GDP				
Discount Rate				
3 percent	1.2%	2.9%	5.0%	11.2%
0 percent	6.3%	19.4%	23.2%	68.1%
2011 GDP	1,463.6	1,622.1	1,463.6	1,622.1

Sources: Authors' calculations.

We calculated cumulative economic damages at two different discount rates, 3 percent and 0 percent (no discounting). The highest damages occur in the A2-world markets scenario, where the cost of total damages from inundation is $380 billion at 3 percent and $2.1 trillion at 0 percent, and the cost of climate-induced inundation is $182 billion and $1.1 trillion, respectively. Cumulative climate-induced damages as a share of 2011 GDP at the 3 percent discount rate are 1.2 percent in B1-local stewardship, 2.9 percent in B1-world markets, 5.0 percent in A2-local stewardship, and 11.2 percent in A2-world markets.

5a. Economic Impacts in Detail

The total economic costs of inundation are driven primarily by damage to dwellings (Table 18 and Table 19); most of the dollar value of damages occurs in British Columbia (a finding discussed in more detail in the section below on the distributional consequences of climate change). Damages to agricultural property and forests are on a lower order of magnitude than those to dwellings, and have little impact on total damages. It is important to reiterate here, however, that our estimates exclude areas that are already at or below sea level, such as "reclaimed" wetlands protected by dikes. Large swaths of New Brunswick's, Nova Scotia's and British Columbia's agricultural land are diked lowlands, including the Fraser Valley in British Columbia, one of Canada's prime food-growing regions. Dwellings damages are strongly influenced by the assumptions used regarding the average value of dwellings, which vary by socioeconomic scenario and year. Dwelling values are assumed to be proportional to per capita GDP, which declines over time in the local stewardship scenario.

Economic damages to agricultural land and buildings (Table 20 and Table 21) are higher in the local-stewardship scenarios, where the amount of total agricultural land is assumed to increase over time, than under world markets, where total agricultural land decreases. Economic damages to forest areas (Table 22 and Table 23) differ by climate scenario, but not by socioeconomic scenario. The value per km^2 of forest land is assumed – for lack of data – to stay constant over time. Annual forest damages decline in all three climate scenarios, therefore, as a result of topography, as discussed above. Total annual economic damages by province or territory are reported in Table 24 andTable 25.

As an additional result, we present the area of fresh surface water exposed to inundation, but do not set a monetary value on these damages (Table 26 and Table 27). Note that fresh water areas are assumed to remain unchanged across all three climate scenarios. The additional fresh surface water exposed to climate-induced inundation reaches 700 km^2 in the 2080s under B1 and 1,600 km^2 under A2.

Table 18: Annual dwellings damages from inundation (millions CAD2008)

	Current Climate LS			Current Climate WM			B1 LS		
Province	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
British Columbia									
SLR	1	2	3	2	5	11	5	8	11
Storm surge	1,399	2,214	3,458	2,017	5,327	13,912	1,637	3,046	5,339
Total	**1,401**	**2,215**	**3,461**	**2,019**	**5,332**	**13,923**	**1,642**	**3,054**	**5,350**
Manitoba									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	1	0	0	1	1	1	1	0	0
Total	**1**	**0**	**0**	**1**	**1**	**1**	**1**	**0**	**0**
New Brunswick									
SLR	1	2	2	2	4	9	2	3	5
Storm surge	359	537	788	517	1,288	3,163	361	546	810
Total	**360**	**538**	**790**	**518**	**1,292**	**3,172**	**363**	**549**	**815**
Newfoundland and Labrador									
SLR	0	0	0	0	1	2	0	0	1
Storm surge	40	52	64	57	123	255	42	58	78
Total	**40**	**52**	**64**	**57**	**124**	**256**	**42**	**59**	**78**
Northwest Territories									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	1	1	0	0	0
Total	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**
Nova Scotia									
SLR	1	2	3	2	4	10	2	3	4
Storm surge	215	306	429	308	734	1,718	212	293	390
Total	**216**	**308**	**432**	**310**	**738**	**1,728**	**214**	**296**	**395**
Nunavut									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	54	79	112	78	191	447	59	100	152
Total	**54**	**79**	**112**	**78**	**191**	**447**	**59**	**100**	**152**
Ontario									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Prince Edward Island									
SLR	0	0	0	0	0	1	0	0	0
Storm surge	39	60	92	56	145	371	40	64	102
Total	**39**	**60**	**92**	**56**	**145**	**372**	**40**	**64**	**102**
Quebec									
SLR	0	0	0	0	0	0	1	1	1
Storm surge	186	271	387	268	649	1,552	187	274	397
Total	**186**	**271**	**387**	**268**	**649**	**1,552**	**188**	**275**	**399**
Yukon Territory									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Canada Total									
SLR	4	6	8	5	14	33	10	16	23
Storm surge	2,293	3,519	5,331	3,302	8,458	21,420	2,538	4,383	7,269
Total	**2,296**	**3,525**	**5,339**	**3,307**	**8,472**	**21,453**	**2,549**	**4,398**	**7,291**

Sources: Authors' calculations.

Table 18 (cont.): Annual dwellings damages from inundation (millions CAD2008)

	B1 WM			A2 LS			A2 WM		
Province	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
British Columbia									
SLR	7	18	44	13	19	28	19	46	112
Storm surge	2,378	7,372	21,565	2,650	5,333	9,629	3,870	12,933	38,919
Total	**2,385**	**7,390**	**21,609**	**2,663**	**5,352**	**9,657**	**3,888**	**12,979**	**39,031**
Manitoba									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	1	1	2	1	1	1	2	3	4
Total	**1**	**1**	**2**	**1**	**1**	**1**	**2**	**3**	**4**
New Brunswick									
SLR	3	8	18	4	6	9	6	15	38
Storm surge	521	1,312	3,253	407	626	1,007	587	1,503	4,063
Total	**524**	**1,319**	**3,272**	**411**	**632**	**1,016**	**593**	**1,518**	**4,101**
Newfoundland and Labrador									
SLR	0	1	3	1	1	1	1	2	5
Storm surge	60	139	310	53	83	133	77	201	539
Total	**60**	**140**	**313**	**54**	**84**	**134**	**77**	**203**	**544**
Northwest Territories									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	0	1	1	0	0	0	0	1	1
Total	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**1**
Nova Scotia									
SLR	3	7	18	4	6	9	5	13	36
Storm surge	304	701	1,559	215	258	279	307	613	1,110
Total	**307**	**708**	**1,577**	**219**	**264**	**288**	**313**	**626**	**1,146**
Nunavut									
SLR	0	0	0	0	0	0	0	1	2
Storm surge	86	242	610	76	147	252	111	356	1,017
Total	**86**	**242**	**610**	**77**	**147**	**253**	**111**	**357**	**1,019**
Ontario									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Prince Edward Island									
SLR	0	1	2	0	1	1	1	1	4
Storm surge	57	154	409	48	82	148	70	197	600
Total	**58**	**155**	**411**	**48**	**82**	**148**	**70**	**199**	**603**
Quebec									
SLR	1	2	6	2	3	5	3	8	19
Storm surge	269	658	1,593	202	290	406	290	695	1,625
Total	**270**	**661**	**1,599**	**204**	**294**	**410**	**293**	**703**	**1,644**
Yukon Territory									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Canada Total									
SLR	15	37	90	24	36	53	35	87	215
Storm surge	3,676	10,579	29,303	3,653	6,821	11,854	5,314	16,501	47,879
Total	**3,691**	**10,617**	**29,394**	**3,677**	**6,857**	**11,908**	**5,349**	**16,588**	**48,094**

Sources: Authors' calculations.

Table 19: Annual dwellings damages from climate inundation (millions CAD2008)

	B1 LS			B1 WM			A2 LS			A2 WM		
Province	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
British Columbia												
SLR	4	6	8	5	14	33	12	17	25	17	42	101
Storm surge	237	833	1,881	361	2,045	7,653	1,251	3,120	6,171	1,853	7,606	25,007
Total	**241**	**838**	**1,889**	**367**	**2,059**	**7,686**	**1,262**	**3,137**	**6,196**	**1,870**	**7,647**	**25,108**
Manitoba												
SLR	0	0	0	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	1	1	1	1	1	2	3
Total	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**1**	**1**	**1**	**2**	**3**
New Brunswick												
SLR	1	2	2	2	4	9	3	5	7	5	11	29
Storm surge	3	10	22	4	24	90	48	89	218	70	215	900
Total	**4**	**11**	**24**	**6**	**27**	**100**	**52**	**94**	**225**	**75**	**227**	**929**
Newfoundland and Labrador												
SLR	0	0	0	0	0	1	0	1	1	1	1	3
Storm surge	2	6	14	3	16	55	13	32	69	20	77	284
Total	**2**	**7**	**14**	**3**	**16**	**57**	**14**	**32**	**70**	**20**	**79**	**287**
Northwest Territories												
SLR	0	0	0	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Nova Scotia												
SLR	1	1	2	1	3	7	3	4	6	4	9	26
Storm surge	-3	-13	-39	-4	-33	-159	0	-48	-150	-1	-121	-608
Total	**-2**	**-12**	**-37**	**-3**	**-30**	**-151**	**3**	**-44**	**-144**	**3**	**-112**	**-583**
Nunavut												
SLR	0	0	0	0	0	0	0	0	0	0	1	2
Storm surge	5	21	40	7	51	163	22	67	141	33	165	570
Total	**5**	**21**	**40**	**7**	**51**	**163**	**22**	**67**	**141**	**33**	**166**	**572**
Ontario												
SLR	0	0	0	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Prince Edward Island												
SLR	0	0	0	0	0	1	0	0	1	0	1	3
Storm surge	1	4	9	2	10	39	9	22	55	14	53	229
Total	**1**	**4**	**10**	**2**	**10**	**39**	**10**	**22**	**56**	**14**	**54**	**232**
Quebec												
SLR	1	1	1	1	2	6	2	3	5	3	8	19
Storm surge	1	4	10	1	9	40	16	20	19	22	46	73
Total	**2**	**5**	**11**	**2**	**12**	**46**	**18**	**23**	**23**	**26**	**54**	**92**
Yukon Territory												
SLR	0	0	0	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Canada Total												
SLR	7	10	14	9	24	57	20	30	45	29	73	182
Storm surge	246	864	1,938	374	2,121	7,883	1,361	3,302	6,523	2,012	8,043	26,459
Total	**252**	**873**	**1,952**	**384**	**2,145**	**7,941**	**1,381**	**3,332**	**6,568**	**2,041**	**8,116**	**26,641**

Sources: Authors' calculations.

Table 20: Annual agriculture damages from inundation (1000s CAD2008)

	Current Climate LS			Current Climate WM			B1 LS		
Province	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
British Columbia									
SLR	0	0	0	0	0	0	0	0	1
Storm surge	57	105	187	55	95	158	91	255	600
Total	**57**	**105**	**188**	**55**	**95**	**158**	**92**	**255**	**600**
Manitoba									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
New Brunswick									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	1	2	3	1	2	3	2	3	7
Total	**2**	**2**	**3**	**1**	**2**	**3**	**2**	**3**	**7**
Newfoundland and Labrador									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Northwest Territories									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Nova Scotia									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	6	9	13	6	8	11	6	11	18
Total	**6**	**9**	**13**	**6**	**8**	**11**	**6**	**11**	**18**
Nunavut									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Ontario									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Prince Edward Island									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	5	8	12	5	7	10	5	9	16
Total	**5**	**8**	**12**	**5**	**7**	**10**	**5**	**9**	**16**
Quebec									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	15	22	33	15	20	28	18	36	71
Total	**15**	**22**	**33**	**15**	**20**	**28**	**18**	**36**	**71**
Yukon Territory									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Canada Total									
SLR	0	0	0	0	0	0	0	1	1
Storm surge	84	146	249	81	132	210	122	314	712
Total	**84**	**146**	**249**	**81**	**132**	**210**	**123**	**314**	**713**

Sources: Authors' calculations.

Table 20 (cont.): Annual agriculture damages from inundation (1000s CAD2008)

	B1 WM			A2 LS			A2 WM		
Province	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
British Columbia									
SLR	0	0	0	0	1	1	0	1	1
Storm surge	88	229	505	217	621	1,476	209	559	1,242
Total	**88**	**230**	**505**	**218**	**621**	**1,477**	**209**	**559**	**1,244**
Manitoba									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
New Brunswick									
SLR	0	0	0	0	0	1	0	0	0
Storm surge	2	3	6	2	4	8	2	3	7
Total	**2**	**3**	**6**	**2**	**4**	**8**	**2**	**4**	**7**
Newfoundland and Labrador									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Northwest Territories									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Nova Scotia									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	6	9	15	7	12	20	7	11	17
Total	**6**	**10**	**15**	**7**	**12**	**20**	**7**	**11**	**17**
Nunavut									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Ontario									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Prince Edward Island									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	5	8	14	6	12	21	6	11	18
Total	**5**	**8**	**14**	**6**	**12**	**22**	**6**	**11**	**18**
Quebec									
SLR	0	0	0	0	0	1	0	0	1
Storm surge	17	32	60	22	48	108	21	43	91
Total	**17**	**32**	**60**	**22**	**48**	**108**	**21**	**43**	**91**
Yukon Territory									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Canada Total									
SLR	0	1	1	1	2	3	1	2	3
Storm surge	118	282	599	254	695	1,633	244	626	1,375
Total	**118**	**283**	**600**	**255**	**697**	**1,636**	**245**	**628**	**1,377**

Sources: Authors' calculations.

Table 21: Annual agriculture damages from climate inundation (1000s CAD2008)

	B1 LS			B1 WM			A2 LS			A2 WM		
Province	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
British Columbia												
SLR	0	0	0	0	0	0	0	1	1	0	1	1
Storm surge	35	150	412	33	135	347	161	515	1,289	154	464	1,084
Total	**35**	**150**	**413**	**33**	**135**	**347**	**161**	**516**	**1,290**	**155**	**465**	**1,086**
Manitoba												
SLR	0	0	0	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
New Brunswick												
SLR	0	0	0	0	0	0	0	0	0	0	0	0
Storm surge	0	1	3	0	1	3	0	2	4	0	1	4
Total	**0**	**1**	**4**	**0**	**1**	**3**	**1**	**2**	**5**	**1**	**2**	**4**
Newfoundland and Labrador												
SLR	0	0	0	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Northwest Territories												
SLR	0	0	0	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Nova Scotia												
SLR	0	0	0	0	0	0	0	0	0	0	0	0
Storm surge	0	2	5	0	2	4	1	3	7	1	3	6
Total	**0**	**2**	**5**	**0**	**2**	**4**	**1**	**3**	**7**	**1**	**3**	**6**
Nunavut												
SLR	0	0	0	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Ontario												
SLR	0	0	0	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Prince Edward Island												
SLR	0	0	0	0	0	0	0	0	0	0	0	0
Storm surge	0	2	4	0	1	4	1	4	9	1	4	8
Total	**0**	**2**	**4**	**0**	**2**	**4**	**1**	**4**	**10**	**1**	**4**	**8**
Quebec												
SLR	0	0	0	0	0	0	0	0	1	0	0	1
Storm surge	3	13	38	3	12	32	6	25	74	6	23	63
Total	**3**	**13**	**38**	**3**	**12**	**32**	**7**	**25**	**75**	**6**	**23**	**63**
Yukon Territory												
SLR	0	0	0	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Canada Total												
SLR	0	1	1	0	0	1	1	2	3	1	1	2
Storm surge	39	168	463	37	151	390	170	549	1,384	163	494	1,165
Total	**39**	**168**	**464**	**37**	**151**	**390**	**171**	**551**	**1,387**	**164**	**496**	**1,167**

Sources: Authors' calculations.

Table 22: Annual forest damages from inundation (1000s CAD2008)

	Current Climate LS			Current Climate WM			B1 LS		
Province	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
British Columbia									
SLR	0	0	0	0	0	0	1	1	1
Storm surge	247	300	352	247	300	352	355	576	796
Total	**247**	**300**	**353**	**247**	**300**	**353**	**356**	**576**	**797**
Manitoba									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	1,310	809	304	1,310	809	304	1,376	981	581
Total	**1,310**	**809**	**304**	**1,310**	**809**	**304**	**1,376**	**981**	**581**
New Brunswick									
SLR	2	2	2	2	2	2	3	3	3
Storm surge	516	524	532	516	524	532	521	538	555
Total	**517**	**525**	**534**	**517**	**525**	**534**	**524**	**541**	**558**
Newfoundland and Labrador									
SLR	0	0	0	0	0	0	1	1	1
Storm surge	369	245	120	369	245	120	392	303	214
Total	**370**	**245**	**121**	**370**	**245**	**121**	**393**	**304**	**215**
Northwest Territories									
SLR	1	1	1	1	1	1	1	1	1
Storm surge	248	248	248	248	248	248	248	248	248
Total	**248**	**249**	**249**	**248**	**249**	**249**	**249**	**249**	**249**
Nova Scotia									
SLR	1	1	1	1	1	1	1	1	1
Storm surge	130	138	146	130	138	146	133	147	161
Total	**130**	**138**	**146**	**130**	**138**	**146**	**134**	**148**	**162**
Nunavut									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	5,998	5,819	5,257	5,998	5,819	5,257	6,059	6,014	5,968
Total	**5,998**	**5,819**	**5,257**	**5,998**	**5,819**	**5,257**	**6,059**	**6,014**	**5,968**
Ontario									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	11,359	9,815	7,880	11,359	9,815	7,880	11,667	11,026	10,074
Total	**11,359**	**9,815**	**7,880**	**11,359**	**9,815**	**7,880**	**11,667**	**11,026**	**10,074**
Prince Edward Island									
SLR	0	0	0	0	0	0	1	1	1
Storm surge	136	139	142	136	139	142	138	142	147
Total	**137**	**140**	**142**	**137**	**140**	**142**	**138**	**143**	**148**
Quebec									
SLR	0	0	0	0	0	0	1	1	1
Storm surge	4,694	4,221	3,543	4,694	4,221	3,543	4,806	4,634	4,422
Total	**4,694**	**4,221**	**3,543**	**4,694**	**4,221**	**3,543**	**4,806**	**4,635**	**4,422**
Yukon Territory									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Canada Total									
SLR	4	4	4	4	4	4	8	8	8
Storm surge	25,006	22,256	18,524	25,006	22,256	18,524	25,695	24,609	23,165
Total	**25,010**	**22,260**	**18,528**	**25,010**	**22,260**	**18,528**	**25,704**	**24,617**	**23,173**

Sources: Authors' calculations.

Table 22 (cont.): Annual forest damages from inundation (1000s CAD2008)

	B1 WM			A2 LS			A2 WM		
Province	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
British Columbia									
SLR	1	1	1	2	2	2	2	2	2
Storm surge	355	576	796	806	1,358	1,910	806	1,358	1,910
Total	**356**	**576**	**797**	**807**	**1,360**	**1,912**	**807**	**1,360**	**1,912**
Manitoba									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	1,376	981	581	1,651	1,483	1,308	1,651	1,483	1,308
Total	**1,376**	**981**	**581**	**1,651**	**1,483**	**1,308**	**1,651**	**1,483**	**1,308**
New Brunswick									
SLR	3	3	3	7	7	7	7	7	7
Storm surge	521	538	555	595	629	679	595	629	679
Total	**524**	**541**	**558**	**601**	**636**	**686**	**601**	**636**	**686**
Newfoundland and Labrador									
SLR	1	1	1	1	1	1	1	1	1
Storm surge	392	303	214	485	468	453	485	468	453
Total	**393**	**304**	**215**	**486**	**469**	**455**	**486**	**469**	**455**
Northwest Territories									
SLR	1	1	1	2	2	2	2	2	2
Storm surge	248	248	248	273	272	262	273	272	262
Total	**249**	**249**	**249**	**275**	**275**	**265**	**275**	**275**	**265**
Nova Scotia									
SLR	1	1	1	2	2	2	2	2	2
Storm surge	133	147	161	161	186	211	161	186	211
Total	**134**	**148**	**162**	**163**	**188**	**214**	**163**	**188**	**214**
Nunavut									
SLR	0	0	0	22	23	23	22	23	23
Storm surge	6,059	6,014	5,968	5,883	5,337	4,792	5,883	5,337	4,792
Total	**6,059**	**6,014**	**5,968**	**5,905**	**5,360**	**4,815**	**5,905**	**5,360**	**4,815**
Ontario									
SLR	0	0	0	22	22	22	22	22	22
Storm surge	11,667	11,026	10,074	12,660	12,412	12,165	12,660	12,412	12,165
Total	**11,667**	**11,026**	**10,074**	**12,682**	**12,435**	**12,187**	**12,682**	**12,435**	**12,187**
Prince Edward Island									
SLR	1	1	1	1	1	1	1	1	1
Storm surge	138	142	147	156	165	178	156	165	178
Total	**138**	**143**	**148**	**158**	**167**	**179**	**158**	**167**	**179**
Quebec									
SLR	1	1	1	14	14	14	14	14	14
Storm surge	4,806	4,634	4,422	5,107	4,952	4,784	5,107	4,952	4,784
Total	**4,806**	**4,635**	**4,422**	**5,121**	**4,966**	**4,798**	**5,121**	**4,966**	**4,798**
Yukon Territory									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Canada Total									
SLR	8	8	8	73	76	76	73	76	76
Storm surge	25,695	24,609	23,165	27,775	27,262	26,742	27,775	27,262	26,742
Total	**25,704**	**24,617**	**23,173**	**27,849**	**27,338**	**26,819**	**27,849**	**27,338**	**26,819**

Sources: Authors' calculations.

Table 23: Annual forest damages from climate inundation (1000s CAD2008)

	B1 LS			B1 WM			A2 LS			A2 WM		
Province	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
British Columbia												
SLR	0	1	1	0	1	1	2	2	2	2	2	2
Storm surge	109	276	444	109	276	444	559	1,058	1,557	559	1,058	1,557
Total	**109**	**277**	**444**	**109**	**277**	**444**	**561**	**1,060**	**1,559**	**561**	**1,060**	**1,559**
Manitoba												
SLR	0	0	0	0	0	0	0	0	0	0	0	0
Storm surge	66	172	277	66	172	277	341	674	1,004	341	674	1,004
Total	**66**	**172**	**277**	**66**	**172**	**277**	**341**	**674**	**1,004**	**341**	**674**	**1,004**
New Brunswick												
SLR	2	2	2	2	2	2	5	5	5	5	5	5
Storm surge	6	14	23	6	14	23	79	105	147	79	105	147
Total	**7**	**16**	**24**	**7**	**16**	**24**	**84**	**110**	**152**	**84**	**110**	**152**
Newfoundland and Labrador												
SLR	0	0	0	0	0	0	1	1	1	1	1	1
Storm surge	23	58	94	23	58	94	116	223	333	116	223	333
Total	**23**	**59**	**94**	**23**	**59**	**94**	**116**	**224**	**334**	**116**	**224**	**334**
Northwest Territories												
SLR	1	1	1	1	1	1	2	2	2	2	2	2
Storm surge	0	0	0	0	0	0	25	25	15	25	25	15
Total	**1**	**1**	**1**	**1**	**1**	**1**	**26**	**26**	**16**	**26**	**26**	**16**
Nova Scotia												
SLR	0	0	0	0	0	0	1	2	2	1	2	2
Storm surge	4	9	15	4	9	15	31	48	66	31	48	66
Total	**4**	**10**	**16**	**4**	**10**	**16**	**32**	**50**	**67**	**32**	**50**	**67**
Nunavut												
SLR	0	0	0	0	0	0	22	23	23	22	23	23
Storm surge	61	194	711	61	194	711	-115	-482	-465	-115	-482	-465
Total	**61**	**194**	**711**	**61**	**194**	**711**	**-93**	**-459**	**-442**	**-93**	**-459**	**-442**
Ontario												
SLR	0	0	0	0	0	0	22	22	22	22	22	22
Storm surge	308	1,211	2,194	308	1,211	2,194	1,301	2,597	4,284	1,301	2,597	4,284
Total	**308**	**1,211**	**2,194**	**308**	**1,211**	**2,194**	**1,323**	**2,620**	**4,307**	**1,323**	**2,620**	**4,307**
Prince Edward Island												
SLR	0	0	0	0	0	0	1	1	1	1	1	1
Storm surge	1	3	5	1	3	5	20	26	36	20	26	36
Total	**2**	**4**	**6**	**2**	**4**	**6**	**21**	**27**	**37**	**21**	**27**	**37**
Quebec												
SLR	1	1	1	1	1	1	14	14	14	14	14	14
Storm surge	112	413	878	112	413	878	412	731	1,241	412	731	1,241
Total	**112**	**414**	**879**	**112**	**414**	**879**	**426**	**745**	**1,255**	**426**	**745**	**1,255**
Yukon Territory												
SLR	0	0	0	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Canada Total												
SLR	4	4	4	4	4	4	69	72	72	69	72	72
Storm surge	689	2,353	4,641	689	2,353	4,641	2,769	5,006	8,218	2,769	5,006	8,218
Total	**693**	**2,357**	**4,645**	**693**	**2,357**	**4,645**	**2,838**	**5,077**	**8,290**	**2,838**	**5,077**	**8,290**

Sources: Authors' calculations.

Table 24: Annual total damages from inundation (millions CAD2008)

	Current Climate LS			Current Climate WM			B1 LS		
Province	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
British Columbia									
SLR	1	2	3	2	5	11	5	8	11
Storm surge	1,400	2,214	3,459	2,017	5,327	13,912	1,637	3,047	5,340
Total	**1,401**	**2,216**	**3,461**	**2,019**	**5,332**	**13,923**	**1,642**	**3,054**	**5,351**
Manitoba									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	2	1	1	2	2	1	2	1	1
Total	**2**	**1**	**1**	**2**	**2**	**1**	**2**	**1**	**1**
New Brunswick									
SLR	1	2	2	2	4	9	2	3	5
Storm surge	359	537	789	517	1,289	3,163	362	547	811
Total	**360**	**539**	**791**	**519**	**1,292**	**3,173**	**364**	**550**	**815**
Newfoundland and Labrador									
SLR	0	0	0	0	1	2	0	0	1
Storm surge	40	52	64	57	124	255	42	58	78
Total	**40**	**52**	**65**	**58**	**124**	**257**	**42**	**59**	**79**
Northwest Territories									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	0	0	1	0	1	1	0	0	1
Total	**0**	**0**	**1**	**0**	**1**	**1**	**0**	**0**	**1**
Nova Scotia									
SLR	1	2	3	2	4	10	2	3	4
Storm surge	215	307	429	308	734	1,718	212	293	391
Total	**216**	**308**	**432**	**310**	**739**	**1,729**	**214**	**296**	**395**
Nunavut									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	60	85	117	84	197	453	65	106	158
Total	**60**	**85**	**117**	**84**	**197**	**453**	**65**	**106**	**158**
Ontario									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	11	10	8	11	10	8	12	11	10
Total	**11**	**10**	**8**	**11**	**10**	**8**	**12**	**11**	**10**
Prince Edward Island									
SLR	0	0	0	0	0	1	0	0	0
Storm surge	39	60	92	56	145	371	40	64	102
Total	**39**	**60**	**93**	**56**	**145**	**372**	**40**	**65**	**102**
Quebec									
SLR	0	0	0	0	0	0	1	1	1
Storm surge	191	275	391	273	653	1,556	192	279	402
Total	**191**	**275**	**391**	**273**	**653**	**1,556**	**193**	**280**	**403**
Yukon Territory									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Canada Total									
SLR	4	6	8	5	14	33	10	16	23
Storm surge	2,318	3,542	5,350	3,327	8,481	21,439	2,564	4,408	7,293
Total	**2,321**	**3,547**	**5,358**	**3,332**	**8,494**	**21,472**	**2,575**	**4,423**	**7,315**

Sources: Authors' calculations.

Table 24 (cont.): Annual total damages from inundation (millions CAD2008)

	B1 WM			A2 LS			A2 WM		
Province	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
British Columbia									
SLR	7	18	44	13	19	28	19	46	112
Storm surge	2,379	7,373	21,566	2,651	5,335	9,632	3,871	12,935	38,923
Total	**2,386**	**7,391**	**21,611**	**2,664**	**5,354**	**9,660**	**3,889**	**12,981**	**39,035**
Manitoba									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	2	2	2	3	3	2	4	4	5
Total	**2**	**2**	**2**	**3**	**3**	**2**	**4**	**4**	**5**
New Brunswick									
SLR	3	8	18	4	6	9	6	15	38
Storm surge	521	1,312	3,254	408	626	1,007	588	1,504	4,064
Total	**524**	**1,320**	**3,272**	**412**	**633**	**1,017**	**594**	**1,519**	**4,102**
Newfoundland and Labrador									
SLR	0	1	3	1	1	1	1	2	5
Storm surge	60	139	310	53	84	134	77	201	540
Total	**61**	**140**	**313**	**54**	**85**	**135**	**78**	**203**	**544**
Northwest Territories									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	0	1	1	0	1	1	1	1	1
Total	**0**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**1**
Nova Scotia									
SLR	3	7	18	4	6	9	5	13	36
Storm surge	304	701	1,560	215	259	279	307	613	1,110
Total	**307**	**709**	**1,577**	**219**	**264**	**288**	**313**	**627**	**1,146**
Nunavut									
SLR	0	0	0	0	0	1	0	1	2
Storm surge	92	248	616	82	152	257	117	361	1,022
Total	**92**	**248**	**616**	**82**	**152**	**258**	**117**	**362**	**1,024**
Ontario									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	12	11	10	13	12	12	13	12	12
Total	**12**	**11**	**10**	**13**	**12**	**12**	**13**	**12**	**12**
Prince Edward Island									
SLR	0	1	2	0	1	1	1	1	4
Storm surge	58	155	409	48	82	148	70	197	600
Total	**58**	**155**	**411**	**49**	**82**	**149**	**70**	**199**	**604**
Quebec									
SLR	1	2	6	2	3	5	3	8	19
Storm surge	274	663	1,597	207	295	411	295	700	1,630
Total	**275**	**665**	**1,603**	**209**	**299**	**415**	**299**	**708**	**1,649**
Yukon Territory									
SLR	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Canada Total									
SLR	15	37	91	24	36	53	35	87	215
Storm surge	3,702	10,604	29,327	3,681	6,849	11,883	5,342	16,529	47,907
Total	**3,717**	**10,642**	**29,417**	**3,705**	**6,885**	**11,936**	**5,377**	**16,616**	**48,122**

Sources: Authors' calculations.

Table 25: Annual total damages from climate inundation (millions CAD2008)

	B1 LS			B1 WM			A2 LS			A2 WM		
Province	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
British Columbia												
SLR	4	6	8	5	14	33	12	17	25	17	42	101
Storm surge	237	833	1,881	361	2,045	7,654	1,251	3,121	6,173	1,854	7,607	25,010
Total	**241**	**839**	**1,890**	**367**	**2,059**	**7,687**	**1,263**	**3,139**	**6,199**	**1,870**	**7,649**	**25,111**
Manitoba												
SLR	0	0	0	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	1	1	2	2	2	3	4
Total	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**2**	**2**	**2**	**3**	**4**
New Brunswick												
SLR	1	2	2	2	4	9	3	5	7	5	11	29
Storm surge	3	10	22	4	24	90	49	89	219	71	215	901
Total	**4**	**11**	**25**	**6**	**27**	**100**	**52**	**94**	**226**	**75**	**227**	**929**
Newfoundland and Labrador												
SLR	0	0	0	0	0	1	0	1	1	1	1	3
Storm surge	2	6	14	3	16	56	13	32	70	20	78	285
Total	**2**	**7**	**14**	**3**	**16**	**57**	**14**	**33**	**70**	**20**	**79**	**288**
Northwest Territories												
SLR	0	0	0	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Nova Scotia												
SLR	1	1	2	1	3	7	3	4	6	4	9	26
Storm surge	-3	-13	-39	-4	-33	-159	0	-48	-150	-1	-121	-608
Total	**-2**	**-12**	**-37**	**-3**	**-30**	**-151**	**3**	**-44**	**-144**	**3**	**-112**	**-582**
Nunavut												
SLR	0	0	0	0	0	0	0	0	1	0	1	2
Storm surge	5	21	41	8	51	163	22	67	140	33	165	569
Total	**5**	**21**	**41**	**8**	**51**	**163**	**22**	**67**	**141**	**33**	**165**	**571**
Ontario												
SLR	0	0	0	0	0	0	0	0	0	0	0	0
Storm surge	0	1	2	0	1	2	1	3	4	1	3	4
Total	**0**	**1**	**2**	**0**	**1**	**2**	**1**	**3**	**4**	**1**	**3**	**4**
Prince Edward Island												
SLR	0	0	0	0	0	1	0	0	1	0	1	3
Storm surge	1	4	10	2	10	39	9	22	55	14	53	229
Total	**1**	**4**	**10**	**2**	**10**	**39**	**10**	**22**	**56**	**14**	**54**	**232**
Quebec												
SLR	1	1	1	1	2	6	2	3	5	3	8	19
Storm surge	1	4	11	1	10	41	16	20	20	23	47	74
Total	**2**	**5**	**12**	**2**	**12**	**47**	**18**	**24**	**25**	**26**	**55**	**93**
Yukon Territory												
SLR	0	0	0	0	0	0	0	0	0	0	0	0
Storm surge	0	0	0	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Canada Total												
SLR	7	10	14	9	24	57	20	30	45	29	73	182
Storm surge	247	866	1,943	375	2,124	7,888	1,363	3,307	6,533	2,015	8,049	26,468
Total	**253**	**876**	**1,957**	**384**	**2,147**	**7,946**	**1,384**	**3,338**	**6,578**	**2,044**	**8,122**	**26,650**

Sources: Authors' calculations.

Table 26: Freshwater area exposed to inundation (km²)

Province	Current Climate 2025	Current Climate 2055	Current Climate 2085	B1 2025	B1 2055	B1 2085	A2 2025	A2 2055	A2 2085
British Columbia									
SLR exposure	1	3	4	5	11	18	12	30	48
Storm surge exposure	76	80	85	85	103	122	128	174	220
Total	**77**	**83**	**89**	**90**	**115**	**140**	**140**	**204**	**268**
Manitoba									
SLR exposure	0	0	0	0	0	0	0	0	0
Storm surge exposure	27	17	6	28	20	12	31	29	27
Total	**27**	**17**	**6**	**28**	**20**	**12**	**31**	**29**	**27**
New Brunswick									
SLR exposure	1	2	4	2	4	7	3	9	14
Storm surge exposure	19	19	19	19	19	18	20	20	18
Total	**20**	**21**	**22**	**21**	**23**	**25**	**24**	**28**	**32**
Newfoundland and Labrador									
SLR exposure	0	1	2	1	2	3	1	3	5
Storm surge exposure	19	14	9	20	17	15	25	27	28
Total	**19**	**15**	**11**	**20**	**19**	**17**	**26**	**30**	**33**
Northwest Territories									
SLR exposure	62	157	253	109	277	446	206	522	839
Storm surge exposure	1,145	1,145	1,145	1,145	1,145	1,145	1,259	1,257	1,105
Total	**1,207**	**1,302**	**1,398**	**1,254**	**1,422**	**1,591**	**1,465**	**1,779**	**1,943**
Nova Scotia									
SLR exposure	1	2	3	1	3	4	2	5	8
Storm surge exposure	9	10	11	10	11	13	12	16	18
Total	**10**	**12**	**14**	**11**	**14**	**17**	**14**	**21**	**27**
Nunavut									
SLR exposure	0	0	0	0	0	0	237	602	968
Storm surge exposure	3,166	3,069	2,771	3,200	3,175	3,150	3,115	2,831	2,547
Total	**3,166**	**3,069**	**2,771**	**3,200**	**3,175**	**3,150**	**3,352**	**3,433**	**3,515**
Ontario									
SLR exposure	0	0	0	0	0	0	2	5	7
Storm surge exposure	52	47	37	52	51	48	51	49	46
Total	**52**	**47**	**37**	**52**	**51**	**48**	**53**	**53**	**54**
Prince Edward Island									
SLR exposure	0	1	1	1	2	3	1	3	5
Storm surge exposure	5	5	5	5	5	5	6	5	5
Total	**6**	**6**	**7**	**6**	**7**	**7**	**7**	**8**	**9**
Quebec									
SLR exposure	0	0	0	1	2	3	12	31	49
Storm surge exposure	224	208	178	226	223	217	227	214	198
Total	**224**	**208**	**178**	**227**	**225**	**220**	**239**	**245**	**247**
Yukon Territory									
SLR exposure	2	5	8	3	8	13	6	14	23
Storm surge exposure	29	29	29	29	29	29	32	32	26
Total	**31**	**34**	**37**	**32**	**37**	**42**	**38**	**46**	**49**
Canada Total									
SLR exposure	67	171	274	122	309	497	482	1,224	1,966
Storm surge exposure	4,771	4,643	4,297	4,819	4,799	4,773	4,907	4,653	4,240
Total	**4,838**	**4,814**	**4,571**	**4,941**	**5,109**	**5,270**	**5,390**	**5,877**	**6,205**

Sources: Authors' calculations.

Table 27: Freshwater area exposed to inundation by climate change (km^2)

Province	Rapid Stabilization (B1)			Business As Usual (A2)		
	2025	2055	2085	2025	2055	2085
British Columbia						
SLR exposure	3	9	14	11	28	44
Storm surge exposure	9	23	37	52	93	135
Total	**13**	**32**	**51**	**63**	**121**	**179**
Manitoba						
SLR exposure	0	0	0	0	0	0
Storm surge exposure	1	4	6	4	13	21
Total	**1**	**4**	**6**	**4**	**13**	**21**
New Brunswick						
SLR exposure	1	2	3	3	7	10
Storm surge exposure	0	0	-1	1	1	0
Total	**1**	**2**	**3**	**4**	**7**	**10**
Newfoundland and Labrador						
SLR exposure	0	1	1	1	2	3
Storm surge exposure	1	3	5	7	13	19
Total	**1**	**4**	**6**	**7**	**15**	**22**
Northwest Territories						
SLR exposure	47	120	193	144	365	586
Storm surge exposure	0	0	0	114	112	-40
Total	**47**	**120**	**193**	**258**	**477**	**546**
Nova Scotia						
SLR exposure	0	1	2	1	3	6
Storm surge exposure	0	1	2	3	5	7
Total	**1**	**2**	**4**	**5**	**9**	**13**
Nunavut						
SLR exposure	0	0	0	237	602	968
Storm surge exposure	34	106	378	-52	-238	-224
Total	**34**	**106**	**378**	**186**	**365**	**743**
Ontario						
SLR exposure	0	0	0	2	5	7
Storm surge exposure	0	5	10	0	2	9
Total	**0**	**5**	**10**	**1**	**7**	**16**
Prince Edward Island						
SLR exposure	0	1	1	1	2	3
Storm surge exposure	0	0	0	0	0	0
Total	**0**	**0**	**1**	**1**	**2**	**3**
Quebec						
SLR exposure	1	2	3	12	31	49
Storm surge exposure	2	14	38	3	5	20
Total	**3**	**16**	**42**	**16**	**36**	**69**
Yukon Territory						
SLR exposure	1	3	5	4	9	15
Storm surge exposure	0	0	0	3	3	-3
Total	**1**	**3**	**5**	**7**	**12**	**12**
Canada Total						
SLR exposure	55	139	223	415	1,053	1,692
Storm surge exposure	48	156	476	136	10	-57
Total	**103**	**295**	**699**	**551**	**1,063**	**1,635**

Sources: Authors' calculations.

5b. Effect of Planned Adaptation

We have focused our quantitative analysis on variations of two of the three adaptation measures most strongly recommended by expert stakeholders: sensible development planning, and strategic retreat from the most affected areas. The third highly recommended measure is coastal ecosystem restoration and enhancement of natural barriers; regrettably, the site-specificity of this measure makes it a poor choice for quantification – ecological restorative measures and their costs are strongly dependent on local ecosystems and topography.

In Table 28 and Table 29, Adaptation Measure 1 is sensible development planning: No additional homes are built in any of the areas exposed to inundation by 2100 in this model. This is a zero-cost measure in our analysis; unearned property tax revenue, possible reimbursements to property owners, and unrealized development value are not considered. Adaptation Measure 2 is strategic retreat: As areas enter into the zone at risk of storm surge inundation, they are abandoned, at a cost equal to the value of these homes. Adaptation Measure 3 combines these two policies to calculate their joint effect (Figure 21 and Figure 22). Both measures are strong versions of existing and proposed policies designed to minimize the extent of potential damage.

Table 28: Annual damages in adaptation scenarios, absolute (billions CAD2008) and GDP share

	No Adaptation			Adaptation Measure 1			Adaptation Measure 2			Adaptation Measure 3		
Total Damages	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
CC-LS	2.3	3.5	5.4	2.0	2.9	3.8	0.0	0.1	0.1	0.0	0.0	0.0
CC-WM	3.3	8.5	21.5	2.8	6.3	14.0	0.1	0.3	0.7	0.1	0.2	0.4
B1-LS	2.6	4.4	7.3	2.2	3.5	5.1	0.1	0.1	0.1	0.0	0.1	0.1
B1-WM	3.7	10.6	29.4	3.1	7.8	18.8	0.1	0.4	1.1	0.1	0.3	0.6
A2-LS	3.7	6.9	11.9	3.1	5.5	8.1	0.1	0.2	0.3	0.1	0.1	0.1
A2-WM	5.4	16.6	48.1	4.5	12.1	30.3	0.2	0.7	1.9	0.2	0.4	1.1
Net B1-LS	0.3	0.9	2.0	0.2	0.7	1.3	0.0	0.0	0.1	0.0	0.0	0.0
Net B1-WM	0.4	2.1	7.9	0.3	1.5	4.8	0.0	0.1	0.4	0.0	0.1	0.2
Net A2-LS	1.4	3.3	6.6	1.2	2.6	4.4	0.1	0.1	0.2	0.0	0.1	0.1
Net A2-WM	2.0	8.1	26.6	1.7	5.8	16.2	0.1	0.4	1.2	0.1	0.3	0.7
Damages as a share of each year's GDP												
CC-LS	0.2%	0.2%	0.4%	0.1%	0.2%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CC-WM	0.2%	0.5%	1.3%	0.2%	0.4%	0.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
B1-LS	0.2%	0.3%	0.5%	0.1%	0.2%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
B1-WM	0.2%	0.7%	1.8%	0.2%	0.5%	1.2%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
A2-LS	0.3%	0.5%	0.8%	0.2%	0.4%	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
A2-WM	0.3%	1.0%	3.0%	0.3%	0.7%	1.9%	0.0%	0.0%	0.1%	0.0%	0.0%	0.1%
Net B1-LS	0.0%	0.1%	0.1%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Net B1-WM	0.0%	0.1%	0.5%	0.0%	0.1%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Net A2-LS	0.1%	0.2%	0.4%	0.1%	0.2%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Net A2-WM	0.1%	0.5%	1.6%	0.1%	0.4%	1.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%

Sources: Authors' calculations.

Table 29: Cumulative damages in adaptation scenarios, absolute (billions CAD2008) and GDP share

	CC-LS	CC-WM	B1-LS	B1-WM	A2-LS	A2-WM
No Adaptation						
Absolute damages						
3 percent	91.7	197.4	109.3	244.9	165.2	379.6
0 percent	336.8	999.0	429.4	1,313.3	675.8	2,103.4
Damage as a share of 2011 GDP						
3 percent	6.3%	12.2%	7.5%	15.1%	11.3%	23.4%
0 percent	23.0%	61.6%	29.3%	81.0%	46.2%	129.7%
Adaptation Measure 1						
Absolute damages						
3 percent	75.1	148.2	88.4	180.4	132.1	275.3
0 percent	258.9	693.6	324.1	893.2	502.1	1,405.7
Damage as a share of 2011 GDP						
3 percent	5.1%	9.1%	6.0%	11.1%	9.0%	17.0%
0 percent	17.7%	42.8%	22.1%	55.1%	34.3%	86.7%
Adaptation Measure 2						
Absolute damages						
3 percent	1.5	6.4	2.4	9.2	4.3	15.6
0 percent	5.2	32.0	8.8	48.0	16.2	83.4
Damage as a share of 2011 GDP						
3 percent	0.1%	0.4%	0.2%	0.6%	0.3%	1.0%
0 percent	0.4%	2.0%	0.6%	3.0%	1.1%	5.1%
Adaptation Measure 3						
Absolute damages						
3 percent	0.8	4.0	1.5	5.9	2.8	10.0
0 percent	3.0	19.5	5.3	28.9	10.0	50.0
Damage as a share of 2011 GDP						
3 percent	0.1%	0.2%	0.1%	0.4%	0.2%	0.6%
0 percent	0.2%	1.2%	0.4%	1.8%	0.7%	3.1%
2011 GDP	1,463.6	1,622.1	1,463.6	1,622.1	1,463.6	1,622.1

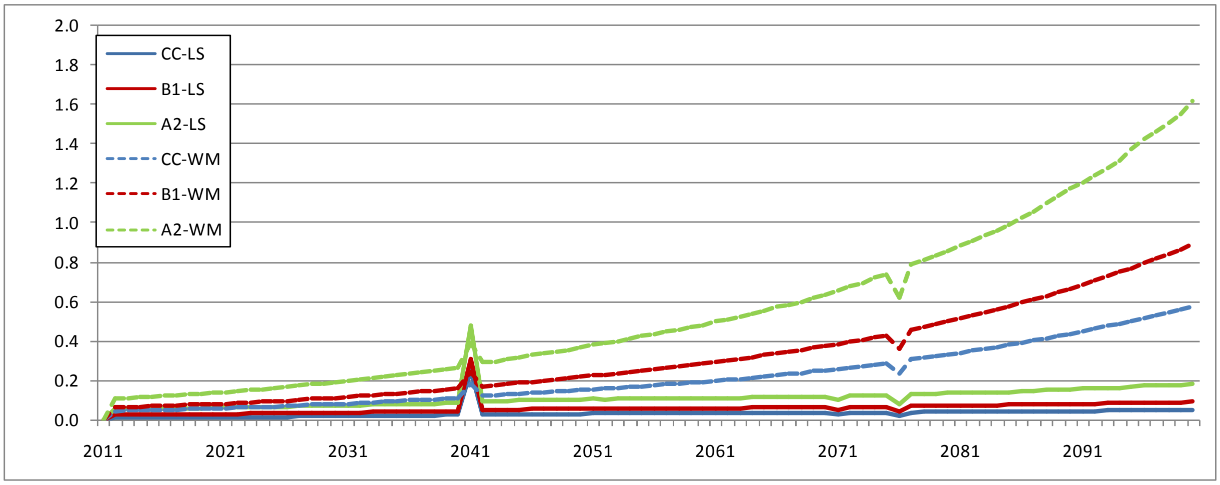
Sources: Authors' calculations.

Table 29 (cont.): Cumulative damages in adaptation scenarios, absolute (billions CAD2008) and GDP share

	Net B1-LS	Net B1-WM	Net A2-LS	Net A2-WM
No Adaptation				
Absolute damages				
3 percent	17.6	47.5	73.5	182.2
0 percent	92.6	314.3	339.0	1,104.5
Damage as a share of 2011 GDP				
3 percent	1.2%	2.9%	5.0%	11.2%
0 percent	6.3%	19.4%	23.2%	68.1%
Adaptation Measure 1				
Absolute damages				
3 percent	13.3	32.2	57.0	127.1
0 percent	65.3	199.6	243.2	712.1
Damage as a share of 2011 GDP				
3 percent	0.9%	2.0%	3.9%	7.8%
0 percent	4.5%	12.3%	16.6%	43.9%
Adaptation Measure 2				
Absolute damages				
3 percent	0.9	2.8	2.8	9.3
0 percent	3.5	16.0	10.9	51.4
Damage as a share of 2011 GDP				
3 percent	0.1%	0.2%	0.2%	0.6%
0 percent	0.2%	1.0%	0.7%	3.2%
Adaptation Measure 3				
Absolute damages				
3 percent	0.7	1.8	2.0	6.0
0 percent	2.3	9.5	7.0	30.5
Damage as a share of 2011 GDP				
3 percent	0.0%	0.1%	0.1%	0.4%
0 percent	0.2%	0.6%	0.5%	1.9%
2011 GDP	1,463.6	1,622.1	1,463.6	1,622.1

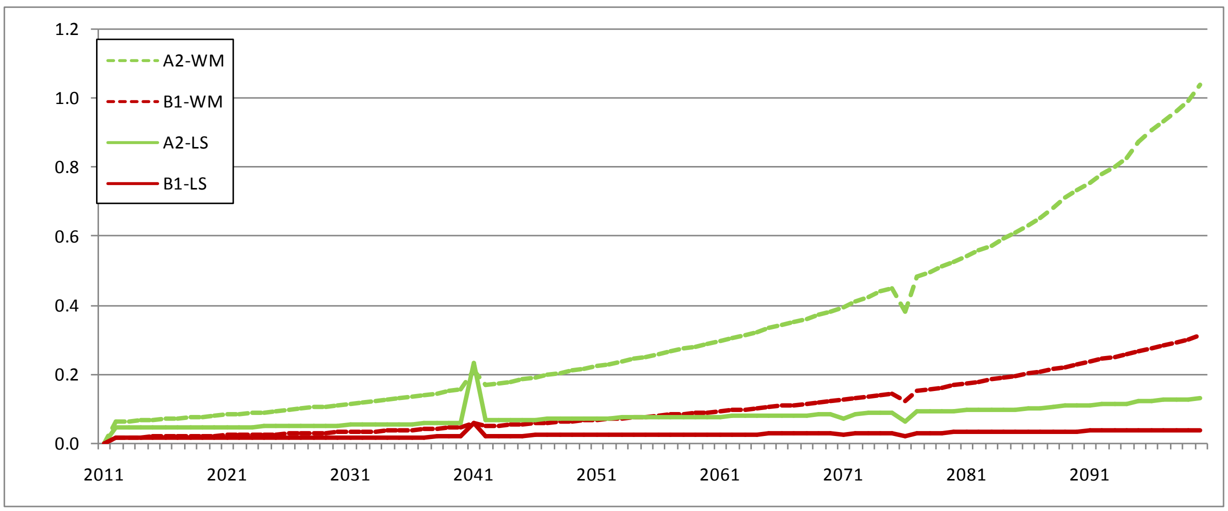
Sources: Authors' calculations.

Figure 21: Adaptation Measure 3, economic damages from inundation (billions CAD2008)



Sources: Authors' calculations.

Figure 22: Adaptation Measure 3, economic climate-induced damages from inundation (billions CAD2008)



Sources: Authors' calculations.

In local-stewardship scenarios, damages are erased by sensible development planning alone, and small net benefits occur. With both adaptations and a rapid-stabilization climate scenario, annual climate-induced damages range from zero to 0.04 percent even in a world-markets scenario. In the A2-world markets scenario, annual climate-induced damages in the 2080s drop by 0.6 percentage points of GDP with sensible development planning; these damages fall from 1.64 percent of GDP to 0.07 percent with strategic retreat, and to 0.04 percent with the combined policies. In the A2-world markets scenario, assuming a 3-percent discount rate, cumulative damages fall from 11.2 percent of 2011 GDP to 7.8 percent with sensible development planning, 0.6 percent with strategic retreat, and 0.4 percent with the combined policies. In the A2-local stewardship scenario, cumulative damages fall from 5.0 percent of 2011 GDP to 3.9 percent with sensible development planning, 0.2 percent with strategic retreat, and 0.1 percent with the combined policies.

We have selected these two adaptation measures for quantification with the full realization that the most "popular" adaptation measure among owners of coastal property is the construction of seawalls or other barriers. Hard barriers are not, however, a preferred choice of planners, policy-makers, or ecologists; on the contrary, given their cost, maintenance requirements, and especially their interference with coastal ecosystems that serve as natural buffers, they are actively discouraged. In addition, in a study of this scale – the entire coastline of Canada – cost estimates for hard barrier construction and maintenance over 90 years could not be made with any certainty: Local conditions have an important impact on the cost per linear meter, as do choices of what areas will and will not be protected. A projection that applied one cost per linear meter to the whole of Canada's coastline at risk of inundation would be of little value (Drozdz 2008).

SECTION 6: DISCUSSION

6a. Distributional Outcomes

Climate damages are not distributed equally among coastal provinces, and the population exposed to these damages is not representative of the national population. By far the greatest share of economic damages occurs in British Columbia, with the Atlantic provinces together accounting for a sizeable, but smaller, share. Visible minorities and the Aboriginal population are over-represented among those exposed to inundation. In British Columbia, Nunavut, and the Northwest Territories, these groups account for more than nine-tenths of the people living in areas exposed to inundation. The exposed population is also poorer than the general public in every province and territory, and in every future scenario.

By province or territory

Economic damages in British Columbia far exceed damages in any other province or territory, in every scenario and every time period (Table 30 and Table 31). British Columbia has the only large urban area – Vancouver/Victoria – in Canada's coastal zone, which is home to more than half its population;[33] provincial 30-year average total damages range from 60 to 81 percent of the national total, while climate-induced damages range from 91 to 97 percent of the total. British Columbia's share of national damages is greater in the A2 scenario than in B1 and current climate.

Table 30: Total province or territory economic damages as a share of national damages

	CC LS			CC WM			B1 LS		
	2025	2055	2085	2025	2055	2085	2025	2055	2085
British Columbia	0.60	0.62	0.65	0.61	0.63	0.65	0.64	0.69	0.73
Manitoba	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
New Brunswick	0.16	0.15	0.15	0.16	0.15	0.15	0.14	0.12	0.11
Newfoundland	0.02	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.01
Northwest Territories	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nova Scotia	0.09	0.09	0.08	0.09	0.09	0.08	0.08	0.07	0.05
Nunavut	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ontario	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Prince Edward Island	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01
Quebec	0.08	0.08	0.07	0.08	0.08	0.07	0.07	0.06	0.06
Yukon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Canada	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

[33] The Vancouver metropolitan area had 2.1 million residents as of 2006, and Victoria, 330,000, for a combined 2.4 million, or 57.1 percent of British Columbia's 4.2 million total (authors' calculations based on Statistics Canada 2006 Census data, http://www12.statcan.ca/english/census06/data/popdwell/Table.cfm?T=201&S=3&O=D&RPP=150).

	B1 WM			A2 LS			A2 WM		
	2025	2055	2085	2025	2055	2085	2025	2055	2085
British Columbia	0.64	0.69	0.73	0.72	0.78	0.81	0.72	0.78	0.81
Manitoba	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
New Brunswick	0.14	0.12	0.11	0.11	0.09	0.09	0.11	0.09	0.09
Newfoundland	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Northwest Territories	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nova Scotia	0.08	0.07	0.05	0.06	0.04	0.02	0.06	0.04	0.02
Nunavut	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ontario	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Prince Edward Island	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Quebec	0.07	0.06	0.05	0.06	0.04	0.03	0.06	0.04	0.03
Yukon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Canada	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Source: Authors' calculations.

Table 31: Climate-induced province or territory economic damages as a share of national damages

	B1 LS			B1 WM			A2 LS			A2 WM		
	2025	2055	2085	2025	2055	2085	2025	2055	2085	2025	2055	2085
British Columbia	0.95	0.96	0.97	0.95	0.96	0.97	0.91	0.94	0.94	0.91	0.94	0.94
Manitoba	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
New Brunswick	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.03	0.03	0.04	0.03	0.03
Newfoundland	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Northwest Territories	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nova Scotia	-0.01	-0.01	-0.02	-0.01	-0.01	-0.02	0.00	-0.01	-0.02	0.00	-0.01	-0.02
Nunavut	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Ontario	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Prince Edward Island	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01
Quebec	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00
Yukon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Canada	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Source: Authors' calculations.

Total damages in the Atlantic provinces together account for 17 to 36 percent of the national total, and damages in these provinces grow smaller as sea levels rise. Climate induced damages in the Atlantic provinces account for 1 percent of total damages in the 2080s in the B1-local stewardship and B1-world markets scenarios, and 4 percent of total damages in the A2-local stewardship and A2-world markets scenarios. Economic damages in Manitoba, Ontario, and the territories do not contribute appreciably to national damages.

By race/ethnicity

Table 32 and Table 33 report the exposure of visible minorities to inundation as compared to the general population. Eighty to 94 percent of the people exposed to climate-induced inundation are visible minorities; the vast majority of the visible minority population exposed to climate change lives in British Columbia. Indeed, visible minorities exposed appear to exceed population exposed; this is an artifact of an extreme concentration of visible minorities in areas exposed to inundation, combined with relatively high growth rates for this population. (The share of visible minorities in these areas is so high that the provincial rate of population growth underestimates the true population growth in the inundated zone.) Overall, the share of visible minorities exposed to climate-induced inundation is more than twice this group's share of the Canadian population. Table 34 and Table 35 tell a similar story regarding the Aboriginal population. All or nearly all of the population exposed to inundation in Nunavut and the Northwest Territories is Aboriginal; the same is true for more than one-third of the exposed population in Manitoba and nearly 20 percent in Quebec. The Aboriginal population exposed to climate-induced inundation is 1.4 to 2.3 times this group's share of the Canadian population. Here again, the share of the Aboriginal population in the inundated zone is greater than 1 for some provinces or territories; the concentration of the Aboriginal population in inundated areas is so high that the provincial rate of population growth tends to underestimate the true total population.

By average household income

Average household income is lower in the areas exposed to inundation than in the province or territory as a whole for every province or territory, every scenario, and every 30-year time slice (Table 36). For Canada as a whole, average household income in the areas exposed to inundation is 55 to 59 percent of the national average.[34] However, there are substantial regional differences: In the Northwest Territories, the average income in areas exposed to inundation is a quarter of the general-population average; in Newfoundland, it's 56 to 75 percent, and in British Columbia, 64 to 71 percent. In most of the rest of the country, the income differences are much smaller. It is worth noting that substantial income gaps show up in all scenarios, even though the average household incomes for the total population vary almost fourfold by economic scenario, from $130,800 per year for Canada as a whole by the 2080s under local stewardship, to $488,100 under world markets (in the 2020s, they are $78,200 and $113,400, respectively). Damage estimates reflect the disproportionate presence of poorer households, and less-expensive homes, in the inundated areas. The projected value of homes has its basis in the actual value of homes in these areas, which are less expensive than they would be in a richer area.

[34] In the context of this model, value results cannot be presented as net of the baseline scenarios.

Table 32: Visible minorities' exposure to inundation

Share of visible minority population for entire province or territory

	CS			LS			WM		
	2025	2055	2085	2025	2055	2085	2025	2055	2085
British Columbia	0.39	0.49	0.49	0.39	0.49	0.49	0.39	0.49	0.49
Manitoba	0.13	0.15	0.15	0.13	0.15	0.15	0.13	0.15	0.15
New Brunswick	0.03	0.05	0.05	0.03	0.05	0.05	0.03	0.05	0.05
Newfoundland	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.03	0.03
Northwest Terr.	0.07	0.09	0.09	0.07	0.09	0.09	0.07	0.09	0.09
Nova Scotia	0.06	0.07	0.07	0.06	0.07	0.07	0.06	0.07	0.07
Nunavut	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Ontario	0.41	0.54	0.54	0.41	0.54	0.54	0.41	0.54	0.54
PEI	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.03	0.03
Quebec	0.14	0.18	0.18	0.14	0.18	0.18	0.14	0.18	0.18
Yukon	0.05	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06
Canada	0.28	0.36	0.36	0.28	0.36	0.36	0.28	0.36	0.36

Share of visible minority population for inundated area

	Current Climate LS			Current Climate WM			B1 LS			B1 WM			A2 LS			A2 WM		
	2025	2055	2085	2025	2055	2085	2025	2055	2085	2025	2055	2085	2025	2055	2085	2025	2055	2085
British Columbia	0.94	1.11	1.11	0.94	1.11	1.11	0.95	1.12	1.12	0.95	1.12	1.12	0.97	1.13	1.13	0.97	1.13	1.13
Manitoba	0.09	0.11	0.11	0.09	0.11	0.11	0.09	0.11	0.11	0.09	0.11	0.11	0.09	0.10	0.11	0.09	0.10	0.11
New Brunswick	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Newfoundland	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02
Northwest Terr.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nova Scotia	0.02	0.02	0.03	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.03	0.03
Nunavut	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Ontario	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
PEI	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02
Quebec	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Yukon	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Canada	0.42	0.52	0.54	0.42	0.52	0.54	0.46	0.61	0.66	0.46	0.61	0.66	0.56	0.73	0.78	0.56	0.73	0.78

Ratio of share of visible minorities in inundated area to share of visible minorities in entire province or territory

	Current Climate LS			Current Climate WM			B1 LS			B1 WM			A2 LS			A2 WM		
	2025	2055	2085	2025	2055	2085	2025	2055	2085	2025	2055	2085	2025	2055	2085	2025	2055	2085
British Columbia	2.40	2.24	2.25	2.40	2.24	2.25	2.45	2.26	2.27	2.45	2.26	2.27	2.50	2.29	2.29	2.50	2.29	2.29
Manitoba	0.74	0.72	0.72	0.74	0.72	0.72	0.74	0.72	0.72	0.74	0.72	0.72	0.71	0.70	0.72	0.71	0.70	0.72
New Brunswick	1.05	0.96	0.96	1.05	0.96	0.96	1.05	0.95	0.94	1.05	0.95	0.94	1.03	0.92	0.89	1.03	0.92	0.89
Newfoundland	0.33	0.34	0.39	0.33	0.34	0.39	0.36	0.41	0.49	0.36	0.41	0.49	0.47	0.55	0.64	0.47	0.55	0.64
Northwest Terr.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nova Scotia	0.36	0.36	0.37	0.36	0.36	0.37	0.37	0.37	0.39	0.37	0.37	0.39	0.40	0.40	0.42	0.40	0.40	0.42
Nunavut	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.00	1.01	1.03	1.00	1.01	1.01	0.97	0.96	1.01	0.97	0.96
Ontario	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
PEI	0.17	0.21	0.26	0.17	0.21	0.26	0.20	0.27	0.34	0.20	0.27	0.34	0.32	0.38	0.62	0.32	0.38	0.62
Quebec	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.04	0.05	0.05	0.04	0.05
Yukon	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Canada	1.51	1.45	1.50	1.51	1.45	1.50	1.67	1.69	1.82	1.67	1.69	1.82	2.02	2.03	2.16	2.02	2.03	2.16

Source: Authors' calculations.

Table 33: Visible minorities' exposure to climate-induced inundation

Share of visible minority population for entire province or territory

	Current Society			Local Stewardship			World Markets		
	2025	2055	2085	2025	2055	2085	2025	2055	2085
British Columbia	0.39	0.49	0.49	0.39	0.49	0.49	0.39	0.49	0.49
Manitoba	0.13	0.15	0.15	0.13	0.15	0.15	0.13	0.15	0.15
New Brunswick	0.03	0.05	0.05	0.03	0.05	0.05	0.03	0.05	0.05
Newfoundland	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.03	0.03
Northwest Territories	0.07	0.09	0.09	0.07	0.09	0.09	0.07	0.09	0.09
Nova Scotia	0.06	0.07	0.07	0.06	0.07	0.07	0.06	0.07	0.07
Nunavut	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Ontario	0.41	0.54	0.54	0.41	0.54	0.54	0.41	0.54	0.54
Prince Edward Island	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.03	0.03
Quebec	0.14	0.18	0.18	0.14	0.18	0.18	0.14	0.18	0.18
Yukon	0.05	0.06	0.06	0.05	0.06	0.06	0.05	0.06	0.06
Canada	0.28	0.36	0.36	0.28	0.36	0.36	0.28	0.36	0.36

Share of visible minority population for inundated area

	B1 LS			B1 WM			A2 LS			A2 WM		
	2025	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
British Columbia	1.04	1.14	1.14	1.04	1.14	1.14	1.01	1.14	1.14	1.01	1.14	1.14
Manitoba	0.09	0.11	0.11	0.09	0.11	0.11	0.08	0.10	0.11	0.08	0.10	0.11
New Brunswick	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.04	0.04	0.03	0.04	0.04
Newfoundland	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.03	0.03
Northwest Territories	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nova Scotia	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Nunavut	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Ontario	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Prince Edward Island	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.03
Quebec	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Yukon	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Canada	0.84	0.94	0.94	0.84	0.94	0.94	0.80	0.93	0.94	0.80	0.93	0.94

Ratio of share of visible minorities in inundated area to share of visible minorities in entire province or territory

	B1 LS			B1 WM			A2 LS			A2 WM		
	2025	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
British Columbia	2.67	2.31	2.31	2.67	2.31	2.31	2.59	2.31	2.31	2.59	2.31	2.31
Manitoba	0.73	0.72	0.72	0.73	0.72	0.72	0.62	0.68	0.72	0.62	0.68	0.72
New Brunswick	1.02	0.86	0.86	1.02	0.86	0.86	0.97	0.86	0.80	0.97	0.86	0.80
Newfoundland	0.97	1.03	1.04	0.97	1.03	1.04	1.09	1.03	1.02	1.09	1.03	1.02
Northwest Territories	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nova Scotia	0.55	0.50	0.50	0.55	0.50	0.50	0.54	0.50	0.50	0.54	0.50	0.50
Nunavut	0.99	0.93	0.96	0.99	0.93	0.96	0.97	0.93	0.93	0.97	0.93	0.93
Ontario	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Prince Edward Island	0.80	0.69	0.69	0.80	0.69	0.69	0.78	0.69	1.07	0.78	0.69	1.07
Quebec	0.05	0.05	0.06	0.05	0.05	0.06	0.05	0.05	0.06	0.05	0.05	0.06
Yukon	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Canada	3.05	2.60	2.61	3.05	2.60	2.61	2.89	2.59	2.61	2.89	2.59	2.61

Source: Authors' calculations.

Table 34: Aboriginal population's exposure to inundation

Share of Aboriginal population for entire province or territory

	Current Society			Local Stewardship			World Markets		
	2025	2055	2085	2025	2055	2085	2025	2055	2085
British Columbia	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Manitoba	0.19	0.20	0.20	0.19	0.20	0.20	0.19	0.20	0.20
New Brunswick	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Newfoundland	0.06	0.07	0.07	0.06	0.07	0.07	0.06	0.07	0.07
Northwest Terr.	0.62	0.66	0.66	0.62	0.66	0.66	0.62	0.66	0.66
Nova Scotia	0.03	0.04	0.04	0.03	0.04	0.04	0.03	0.04	0.04
Nunavut	0.94	0.98	0.98	0.94	0.98	0.98	0.94	0.98	0.98
Ontario	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
PEI	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02
Quebec	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Yukon	0.29	0.31	0.31	0.29	0.31	0.31	0.29	0.31	0.31
Canada	0.04	0.05	0.05	0.04	0.05	0.05	0.04	0.05	0.05

Share of Aboriginal population for inundated area

	Current Climate LS			Current Climate WM			B1 LS			B1 WM			A2 LS			A2 WM		
	2025	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
British Columbia	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Manitoba	0.39	0.36	0.36	0.39	0.36	0.36	0.41	0.36	0.36	0.41	0.36	0.36	0.71	0.56	0.37	0.71	0.56	0.37
New Brunswick	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Newfoundland	0.05	0.06	0.07	0.05	0.06	0.07	0.05	0.06	0.07	0.05	0.06	0.07	0.05	0.07	0.08	0.05	0.07	0.08
Northwest Terr.	1.29	1.38	1.38	1.29	1.38	1.38	1.29	1.38	1.38	1.29	1.38	1.38	1.29	1.38	1.38	1.29	1.38	1.38
Nova Scotia	0.26	0.26	0.24	0.26	0.26	0.24	0.25	0.23	0.21	0.25	0.23	0.21	0.21	0.19	0.16	0.21	0.19	0.16
Nunavut	1.06	1.14	1.15	1.06	1.14	1.15	1.04	1.09	1.11	1.04	1.09	1.11	1.01	1.03	1.02	1.01	1.03	1.02
Ontario	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
PEI	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Quebec	0.18	0.17	0.16	0.18	0.17	0.16	0.18	0.18	0.18	0.18	0.18	0.18	0.19	0.19	0.18	0.19	0.19	0.18
Yukon	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Canada	0.10	0.09	0.08	0.10	0.09	0.08	0.10	0.09	0.08	0.10	0.09	0.08	0.09	0.08	0.07	0.09	0.08	0.07

Ratio of share of Aboriginal population in inundated area to share of aboriginal population in entire province or territory

	Current Climate LS			Current Climate WM			B1 LS			B1 WM			A2 LS			A2 WM		
	2025	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
British Columbia	0.35	0.34	0.33	0.35	0.34	0.33	0.34	0.31	0.30	0.34	0.31	0.30	0.30	0.29	0.28	0.30	0.29	0.28
Manitoba	2.07	1.80	1.80	2.07	1.80	1.80	2.20	1.80	1.80	2.20	1.80	1.80	3.81	2.75	1.83	3.81	2.75	1.83
New Brunswick	0.83	0.86	0.88	0.83	0.86	0.88	0.86	0.91	0.95	0.86	0.91	0.95	0.96	1.02	1.04	0.96	1.02	1.04
Newfoundland	0.76	0.88	1.02	0.76	0.88	1.02	0.78	0.92	1.06	0.78	0.92	1.06	0.85	1.00	1.14	0.85	1.00	1.14
Northwest Terr.	2.10	2.08	2.08	2.10	2.08	2.08	2.10	2.08	2.08	2.10	2.08	2.08	2.10	2.08	2.08	2.10	2.08	2.08
Nova Scotia	7.43	6.75	6.21	7.43	6.75	6.21	7.11	6.14	5.45	7.11	6.14	5.45	6.09	4.97	4.20	6.09	4.97	4.20
Nunavut	1.13	1.17	1.18	1.13	1.17	1.18	1.11	1.12	1.13	1.11	1.12	1.13	1.07	1.05	1.04	1.07	1.05	1.04
Ontario	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
PEI	1.08	1.12	1.16	1.08	1.12	1.16	1.11	1.16	1.21	1.11	1.16	1.21	1.18	1.24	1.19	1.18	1.24	1.19
Quebec	11.7	10.9	10.0	11.7	10.9	10.0	11.9	11.5	11.2	11.9	11.5	11.2	12.7	12.2	11.3	12.7	12.2	11.3
Yukon	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Canada	2.35	2.07	1.85	2.35	2.07	1.85	2.25	1.91	1.68	2.25	1.91	1.68	2.02	1.68	1.44	2.02	1.68	1.44

Source: Authors' calculations.

Table 35: Aboriginal population's exposure to climate-induced inundation

Share of Aboriginal population for entire province or territory									
	Current Society			**Local Stewardship**			**World Markets**		
	2085	2025	2055	2085	2025	2055	2085	2025	2055
British Columbia	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Manitoba	0.19	0.20	0.20	0.19	0.20	0.20	0.19	0.20	0.20
New Brunswick	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Newfoundland	0.06	0.07	0.07	0.06	0.07	0.07	0.06	0.07	0.07
Northwest Territories	0.62	0.66	0.66	0.62	0.66	0.66	0.62	0.66	0.66
Nova Scotia	0.03	0.04	0.04	0.03	0.04	0.04	0.03	0.04	0.04
Nunavut	0.94	0.98	0.98	0.94	0.98	0.98	0.94	0.98	0.98
Ontario	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Prince Edward Island	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02
Quebec	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Yukon	0.29	0.31	0.31	0.29	0.31	0.31	0.29	0.31	0.31
Canada	0.04	0.05	0.05	0.04	0.05	0.05	0.04	0.05	0.05

Share of Aboriginal population for inundated area												
	B1 LS			**B1 WM**			**A2 LS**			**A2 WM**		
	2025	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
British Columbia	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Manitoba	0.82	0.36	0.36	0.82	0.36	0.36	1.62	0.77	0.37	1.62	0.77	0.37
New Brunswick	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Newfoundland	0.07	0.09	0.09	0.07	0.09	0.09	0.08	0.09	0.09	0.08	0.09	0.09
Northwest Territories	1.33	1.38	1.38	1.33	1.38	1.38	1.31	1.38	1.38	1.31	1.38	1.38
Nova Scotia	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.05	0.04
Nunavut	0.93	0.95	1.00	0.93	0.95	1.00	0.92	0.95	0.96	0.92	0.95	0.96
Ontario	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Prince Edward Island	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Quebec	0.27	0.28	0.29	0.27	0.28	0.29	0.26	0.25	0.22	0.26	0.25	0.22
Yukon	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Canada	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.06	0.05

Ratio of share of Aboriginal population in inundated area to share of aboriginal population in entire province or territory												
	B1 LS			**B1 WM**			**A2 LS**			**A2 WM**		
	2025	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
British Columbia	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
Manitoba	4.39	1.80	1.80	4.39	1.80	1.80	8.72	3.79	1.83	8.72	3.79	1.83
New Brunswick	1.34	1.29	1.29	1.34	1.29	1.29	1.34	1.30	1.24	1.34	1.30	1.24
Newfoundland	1.24	1.30	1.30	1.24	1.30	1.30	1.29	1.30	1.31	1.29	1.30	1.31
Northwest Territories	2.16	2.08	2.08	2.16	2.08	2.08	2.13	2.08	2.08	2.13	2.08	2.08
Nova Scotia	1.36	1.30	1.30	1.36	1.30	1.30	1.34	1.30	1.07	1.34	1.30	1.07
Nunavut	0.99	0.97	1.02	0.99	0.97	1.02	0.98	0.97	0.98	0.98	0.97	0.98
Ontario	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Prince Edward Island	1.50	1.46	1.46	1.50	1.46	1.46	1.49	1.46	1.23	1.49	1.46	1.23
Quebec	17.59	17.78	18.20	17.59	17.78	18.20	16.84	15.68	13.82	16.84	15.68	13.82
Yukon	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Canada	1.36	1.34	1.27	1.36	1.34	1.27	1.45	1.30	1.15	1.45	1.30	1.15

Source: Authors' calculations.

Table 36: Exposure to inundation by average household income

Average household income for entire province or territory									
	Current Society			Local Stewardship			World Markets		
(1000s CAD2008)	2025	2055	2085	2025	2055	2085	2025	2055	2085
British Columbia	95.7	147.3	225.3	73.9	100.0	122.7	107.1	224.7	457.8
Manitoba	75.0	118.9	189.2	72.5	103.5	132.1	105.5	232.9	493.9
New Brunswick	75.7	128.8	218.4	70.9	108.0	147.1	103.2	244.0	550.9
Newfoundland	78.3	143.1	270.9	73.3	119.8	181.9	106.9	271.6	684.7
Northwest Territories	124.4	181.7	271.4	103.3	133.2	159.5	149.4	298.7	595.0
Nova Scotia	81.6	144.9	262.7	76.9	122.4	178.0	112.2	277.1	669.0
Nunavut	101.5	148.2	221.3	84.2	108.7	130.1	121.8	243.6	485.3
Ontario	101.9	153.0	232.0	86.7	115.3	140.2	125.5	258.9	523.1
Prince Edward Island	69.8	107.4	166.4	62.3	85.3	106.0	90.2	191.8	396.0
Quebec	88.0	130.6	197.2	65.8	85.8	103.8	95.2	192.5	387.5
Yukon	97.2	142.0	212.0	80.7	104.1	124.6	116.7	233.4	464.9
Canada	93.5	143.3	220.1	78.2	106.1	130.8	113.4	238.5	488.1
Average household income for inundated area									
	Current Climate LS			**Current Climate WM**			**B1 LS**		
(1000s CAD2008)	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
British Columbia	52.6	71.0	87.3	72.4	151.4	312.2	52.4	70.3	85.9
Manitoba	70.6	100.5	128.9	97.4	214.6	461.9	70.6	100.5	128.9
New Brunswick	62.6	95.3	130.6	86.5	204.2	468.7	62.6	95.3	130.6
Newfoundland	43.2	70.2	107.1	59.8	151.0	386.2	44.0	73.5	115.1
Northwest Territories	26.0	33.5	40.2	35.7	71.2	143.8	26.0	33.5	40.2
Nova Scotia	69.6	108.8	156.7	96.3	233.5	564.0	69.1	106.7	151.8
Nunavut	77.5	100.4	120.7	106.4	213.5	431.5	77.3	99.7	120.1
Ontario	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Prince Edward Island	49.8	69.1	87.6	68.5	147.6	313.5	50.2	70.3	89.9
Quebec	62.1	80.7	98.3	85.3	171.8	351.3	62.1	80.3	96.9
Yukon	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Canada	46.2	62.4	77.3	63.5	133.1	276.3	46.1	62.1	76.4
Average household income for inundated area (cont.)									
	B1 WM			**A2 LS**			**A2 WM**		
(1000s CAD2008)	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
British Columbia	72.1	149.8	307.0	51.5	68.0	81.9	70.7	144.9	292.7
Manitoba	97.4	214.6	461.9	70.6	100.5	128.9	97.4	214.6	461.9
New Brunswick	86.5	204.2	468.8	62.6	95.3	130.9	86.5	204.3	469.8
Newfoundland	61.0	158.2	415.5	47.5	83.1	136.1	65.9	179.3	492.3
Northwest Territories	35.7	71.2	143.8	26.0	33.5	40.2	35.7	71.2	143.8
Nova Scotia	95.6	228.8	545.8	67.0	100.7	140.4	92.5	215.8	505.0
Nunavut	106.1	212.1	429.2	76.3	97.7	116.6	104.8	207.7	416.7
Ontario	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Prince Edward Island	69.0	150.2	322.1	51.6	73.8	95.2	71.1	157.6	340.7
Quebec	85.2	170.8	346.5	61.7	80.0	97.2	84.8	170.2	347.5
Yukon	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Canada	63.4	132.4	273.3	45.8	61.6	76.0	63.0	131.4	271.7

Source: Authors' calculations.

Table 36 (cont.): Exposure to inundation by average household income

Ratio of average household income in inundated area to average household income in entire province or territory									
	Current Climate LS			Current Climate WM			B1 LS		
(1000s CAD2008)	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
British Columbia	0.71	0.71	0.71	0.68	0.67	0.68	0.71	0.70	0.70
Manitoba	0.97	0.97	0.98	0.92	0.92	0.94	0.97	0.97	0.98
New Brunswick	0.88	0.88	0.89	0.84	0.84	0.85	0.88	0.88	0.89
Newfoundland	0.59	0.59	0.59	0.56	0.56	0.56	0.60	0.61	0.63
Northwest Territories	0.25	0.25	0.25	0.24	0.24	0.24	0.25	0.25	0.25
Nova Scotia	0.91	0.89	0.88	0.86	0.84	0.84	0.90	0.87	0.85
Nunavut	0.92	0.92	0.93	0.87	0.88	0.89	0.92	0.92	0.92
Ontario	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Prince Edward Island	0.80	0.81	0.83	0.76	0.77	0.79	0.81	0.82	0.85
Quebec	0.94	0.94	0.95	0.90	0.89	0.91	0.94	0.94	0.93
Yukon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Canada	0.59	0.59	0.59	0.56	0.56	0.57	0.59	0.59	0.58
Ratio of average household income in inundated area to entire province or territory (cont.)									
	B1 WM			A2 LS			A2 WM		
(1000s CAD2008)	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**	**2025**	**2055**	**2085**
British Columbia	0.67	0.67	0.67	0.70	0.68	0.67	0.66	0.64	0.64
Manitoba	0.92	0.92	0.94	0.97	0.97	0.98	0.92	0.92	0.94
New Brunswick	0.84	0.84	0.85	0.88	0.88	0.89	0.84	0.84	0.85
Newfoundland	0.57	0.58	0.61	0.65	0.69	0.75	0.62	0.66	0.72
Northwest Territories	0.24	0.24	0.24	0.25	0.25	0.25	0.24	0.24	0.24
Nova Scotia	0.85	0.83	0.82	0.87	0.82	0.79	0.82	0.78	0.75
Nunavut	0.87	0.87	0.88	0.91	0.90	0.90	0.86	0.85	0.86
Ontario	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Prince Edward Island	0.77	0.78	0.81	0.83	0.86	0.90	0.79	0.82	0.86
Quebec	0.90	0.89	0.89	0.94	0.93	0.94	0.89	0.88	0.90
Yukon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Canada	0.56	0.56	0.56	0.59	0.58	0.58	0.56	0.55	0.56

Source: Authors' calculations.

6b. Role of Planned Adaptation

The potential property damage to coastal Canada from climate change is serious, and the distribution of these impacts is far from equal: Those most affected are likely to be poorer than average, by province or territory, and to come disproportionately from visible minority or Aboriginal populations. A few simple, straightforward adaptation measures would greatly reduce these damages. Canada's coastline is changing; the highest future damages would result from a refusal to acknowledge and adjust to these changes. If public planners instead embrace – and enforce – forward-thinking zoning laws appropriate to Canada's future coastline, much property damage can be avoided.

Sensible development planning requires that no additional development be permitted in areas at risk of future sea-level rise and storm surges. In the A2-world markets scenario, this adaptation measure lowers cumulative future coastal damages by over 30 percent (at a 3-percent discount rate). It is important to recall that these damage estimates include only residential property, agricultural land and buildings, and forest land. If new development along low-lying coastlines were to include stores and hotels, roads and sewage lines, factories and power plants, these damages would be far higher – and the savings from this adaptation measure that much greater.

Strategic withdrawal from areas as they begin to flood lowers cumulative damages even more, by 95 percent. Without this adaptation measure, home-owners rebuild each time they sustain damage in a storm. With this measure enforced as public policy, damaged homes are abandoned and the price of rebuilding them is invested instead into homes in less risky areas. With both adaptation measures in effect, cumulative damages are just 3 percent of the costs without adaptation to climate change. Again, if these damage estimates were expanded to include commercial, industrial and public property and infrastructure, the costs of climate change and the savings from adaptation would be much higher.

6c. Policy Implications

The results of this study have clear policy implications for Canadian national, regional and local authorities. Coastal damages from climate change can be reduced by means of forward-thinking planning and zoning. Here we offer several policy recommendations regarding improved accuracy of future sea-level rise studies, and the implementation of adaptation measures similar to those quantified in this report.

- Develop "model" policies that incorporate these strategies, and adopt them at the province and territory level, with protected zones defined by law (e.g. all beaches, dunes, and coastal wetlands, plus a restricted-development area within 30 meters of those zones, as is New Brunswick's policy), and the ability for local authorities to impose further, but not fewer, restrictions. To prevent a maladaptive rush to develop coastal land prior to implementation, consider a development moratorium in the affected areas while policies are being drafted, and do not allow the adoption process to stretch out for more than one year – even if a choice is made to phase in the strictest measures.
- Develop more precise sea-level rise and storm-surge projections for the entire Canadian coast, with a special focus on densely populated areas, and develop a system to regularly update the data and monitor the coastal landscape for erosion and other issues. Greater precision in these estimates will require better elevation data, and a large, well-funded national study to enable far greater local detail in the physical model. Areas at or below sea level should be analyzed more closely, to gauge their exposure to sea-level rise and storm surges and the effectiveness of dikes and other existing barriers.
- Strengthen province/territory and local capacity to develop and implement adaptation plans by continuing to fund projects such as the Regional Adaptation Collaboratives; bringing together land-use and environmental experts and enforcers within government (as New Brunswick has done in its Department of Environment); making it easy for local authorities to obtain crucial information and call in experts to assist them; and funding training opportunities.
- Educate and engage the public, directly (through the media, websites, etc.) and especially through businesses and professionals likely to interact with home-owners and developers and with a possible stake in mitigating losses – property insurers, banks, real-estate agents, construction companies, architects, landscapers.
- Seriously consider the implications of economic and environmental choices beyond coastal-zones management: A local-stewardship economy would sharply reduce climate-related losses in the future, but it would require a major shift in priorities. Rapid stabilization of greenhouse gas emissions cannot be achieved by Canada alone, but Canada can choose its role in reducing emissions, and either be a leader, or a straggler. We recommend fostering nationwide debate of these issues.

The impact of climate change on rising seas and storm surges has already been set in motion. The inundation of Canada's coastlines is almost certain to be at least as extensive as shown here in the rapid-stabilization scenario, and most likely, far worse. Global emissions of greenhouse gases are accelerating at what will be a great cost of Canada and to nations around the world. There is a role for Canada to play in reducing these emissions and in negotiating reductions in other countries. There is also a role for it to play in protecting its own residents and assuring that future damages will be as small as possible through adaptation investments. Careful development planning today will go a great way towards limiting future damage costs.

APPENDIX A: ECONOMIC MODEL

For sea-level rise:

(1) $\hat{X}_{trs} = X_{m_1 r} + (S_{trs} - m_1)(X_{m_2 r} - X_{m_1 r})$

(2) $S_{trs} = t(slr_{ts} + su_{tr})$

(3) **Aggregate regions into provinces or territories: $\hat{X}_{trs} \rightarrow \hat{X}_{tps}$; aggregation rule will vary by variable**

(4) $\hat{X}_{tpse} = \hat{X}_{tps}\left(\frac{x_{tpe}}{x_{tpe_b}}\right)$

Where:

$\hat{X}_{trs}$ = variable value by year, climate scenario, and region

t = years; 2011 to 2100 where t = 1 in 2011

r = region, including provinces, territories, and subdivisions of provinces or territories such that only one relative sea-level rise rate applies to each region

s = climate change scenario (current climate, rapid stabilization, business as usual)

X_{mr} = variable value by meta-scenario and region (GIS output)

m_1 = S_{trs} rounded down to the nearest integer

m_2 = S_{trs} rounded up to the nearest integer

$Strs$ = total projected sea-level rise

slr_{ts} = projected climate change-induced sea-level rise rate (mm/year) by year and climate scenario

su_{tr} = projected relative sea-level rise rate (mm/year) by year and region

p = province or territory

e = socioeconomic scenario (current society, local stewardship, world markets)

$\frac{x_{tpe}}{x_{tp\,e_b}}$ = ratio of projected variable value to baseline value, in the absence of climate change

x = projected variable value in the absence of climate change

e_b = baseline socioeconomic scenario in t = 1

For storm surges:

(5) $\hat{X}_{trs} = [X_{n_1r} + (Z_{trs} - n_1)(X_{n_2r} - X_{n_1r})] - [X_{m_1r} + (S_{trs} - m_1)(X_{m_2r} - X_{m_1r})]$

(6) $Z_{trs} = z + t(slr_{ts} + su_{tr}) = z + S_{trs}$

(7) Aggregate regions into provinces or territories: $\hat{X}_{trs} \rightarrow \hat{X}_{tps}$; aggregation rule will vary by variable

(8) $\hat{X}_{tpse} = \hat{X}_{tps}\left(\frac{x_{tpe}}{x_{tpe_b}}\right) * R_{trs}$

Where:

Z_{trs} = total projected sea-level rise plus storm surge

z = storm surge

R_{trs} = risk of event occurring (inverse return rate)

n_1 = Z_{trs} rounded down to the nearest integer

n_2 = Z_{trs} rounded up to the nearest integer

APPENDIX B: SENSITIVITY ANALYSIS

We tested model results for sensitivity to changes in five key sets of parameters:

- Sea-level rise rate: We tested the B1 rate at 0.18 and 0.38 (per IPCC 2007), and the A2 rate at an increase and decrease of 15 percent (approximated from Rahmstorf 2007).
- Discount rate: We tested 1 percent.
- Relative sea-level rise rates: We tested these rates at the lower and upper bounds of data shown in (Table 10). Where RSLR areas' data had no larger range, we applied the average range for those areas that did.
- Storm-surge severity: We tested these values at the lower and upper bounds of data shown in (Table 12). Where RSLR areas' data had no larger range, we applied the average range for those areas that did.
- Storm-surge frequency: We tested these values at the lower and upper bounds of data shown in (Table 12). Where RSLR areas' data had no larger range, we applied the average range for those areas that did.

The results of these sensitivity tests are shown in Appendix Tables B1 and B2 below. All parameter changes resulted in relatively small differences in model results, with the exceptions of the 1-percent discount rate, which increased the A2-world markets cumulative results (3 percent discount rate) by 216 percent, and of storm-surge frequency, which reduced these results by 42 percent when lower, and increased them by 16 percent when raised. When storm-surge severity decreased, these results were reduced by 15 percent.

In addition, we performed an interval analysis combining the parameter changes from all of the sensitivity tests that resulted in lower economic damages as a lower interval, and all of the changes that resulted in higher economic damages as an upper interval. The lower interval included decreases in SLR rates, decreases in RSLR rates, decreases in storm-surge severity, and decreases in storm surge frequency. The upper interval included increases in SLR rates, increases in RSLR rates, increases in storm-surge severity, and increases in storm surge frequency. We did not include the decreased discount rate in the upper interval. The lower interval changes reduced the A2-world markets cumulative results (3 percent discount rate) by 59 percent, while the upper interval increased these results by 32 percent.

Appendix Table B1: Annual damages in sensitivity tests

	2025	2055	2085	2025	2055	2085	2025	2055	2085
	Base Model			SLR Rate Increase			SLR Rate Decrease		
Total Damages (billions CAD2008)									
CC-LS	2.3	3.5	5.4	2.3	3.5	5.4	2.3	3.5	5.4
CC-WM	3.3	8.5	21.5	3.3	8.5	21.5	3.3	8.5	21.5
B1-LS	2.6	4.4	7.3	2.7	4.7	8.0	2.5	4.1	6.6
B1-WM	3.7	10.6	29.4	3.9	11.4	32.1	3.6	9.9	26.6
A2-LS	3.7	6.9	11.9	3.8	7.2	12.6	3.6	6.6	11.2
A2-WM	5.4	16.6	48.1	5.5	17.4	51.0	5.2	15.8	45.2
Net B1-LS	0.3	0.9	2.0	0.3	1.2	2.6	0.2	0.6	1.3
Net B1-WM	0.4	2.1	7.9	0.5	2.9	10.6	0.2	1.4	5.2
Net A2-LS	1.4	3.3	6.6	1.5	3.7	7.3	1.3	3.0	5.9
Net A2-WM	2.0	8.1	26.6	2.2	8.9	29.5	1.9	7.3	23.7
Damages as a share of each year's GDP									
CC-LS	0.2%	0.2%	0.4%	0.2%	0.2%	0.4%	0.2%	0.2%	0.4%
CC-WM	0.2%	0.5%	1.3%	0.2%	0.5%	1.3%	0.2%	0.5%	1.3%
B1-LS	0.2%	0.3%	0.5%	0.2%	0.3%	0.5%	0.2%	0.3%	0.5%
B1-WM	0.2%	0.7%	1.8%	0.2%	0.7%	2.0%	0.2%	0.6%	1.6%
A2-LS	0.3%	0.5%	0.8%	0.3%	0.5%	0.9%	0.2%	0.4%	0.8%
A2-WM	0.3%	1.0%	3.0%	0.3%	1.1%	3.1%	0.3%	1.0%	2.8%
Net B1-LS	0.0%	0.1%	0.1%	0.0%	0.1%	0.2%	0.0%	0.0%	0.1%
Net B1-WM	0.0%	0.1%	0.5%	0.0%	0.2%	0.7%	0.0%	0.1%	0.3%
Net A2-LS	0.1%	0.2%	0.4%	0.1%	0.2%	0.5%	0.1%	0.2%	0.4%
Net A2-WM	0.1%	0.5%	1.6%	0.1%	0.5%	1.8%	0.1%	0.5%	1.5%

	Discount Rate Decrease			RSLR Rates Decrease			RSLR Rates Increase		
Total Damages (billions CAD2008)									
CC-LS	2.3	3.5	5.4	2.3	3.4	5.0	2.4	3.7	5.7
CC-WM	3.3	8.5	21.5	3.3	8.1	20.2	3.4	8.9	22.8
B1-LS	2.6	4.4	7.3	2.5	4.3	7.0	2.6	4.6	7.6
B1-WM	3.7	10.6	29.4	3.7	10.3	28.2	3.8	11.0	30.7
A2-LS	3.7	6.9	11.9	3.7	6.8	11.7	3.7	7.0	12.2
A2-WM	5.4	16.6	48.1	5.3	16.4	47.0	5.4	16.9	49.4
Net B1-LS	0.3	0.9	2.0	0.3	0.9	2.0	0.3	0.9	1.9
Net B1-WM	0.4	2.1	7.9	0.4	2.2	8.0	0.4	2.1	7.8
Net A2-LS	1.4	3.3	6.6	1.4	3.4	6.6	1.4	3.3	6.6
Net A2-WM	2.0	8.1	26.6	2.1	8.2	26.8	2.0	8.0	26.6
Damages as a share of each year's GDP									
CC-LS	0.2%	0.2%	0.4%	0.2%	0.2%	0.3%	0.2%	0.3%	0.4%
CC-WM	0.2%	0.5%	1.3%	0.2%	0.5%	1.2%	0.2%	0.5%	1.4%
B1-LS	0.2%	0.3%	0.5%	0.2%	0.3%	0.5%	0.2%	0.3%	0.5%
B1-WM	0.2%	0.7%	1.8%	0.2%	0.6%	1.7%	0.2%	0.7%	1.9%
A2-LS	0.3%	0.5%	0.8%	0.3%	0.5%	0.8%	0.3%	0.5%	0.8%
A2-WM	0.3%	1.0%	3.0%	0.3%	1.0%	2.9%	0.3%	1.0%	3.0%
Net B1-LS	0.0%	0.1%	0.1%	0.0%	0.1%	0.1%	0.0%	0.1%	0.1%
Net B1-WM	0.0%	0.1%	0.5%	0.0%	0.1%	0.5%	0.0%	0.1%	0.5%
Net A2-LS	0.1%	0.2%	0.4%	0.1%	0.2%	0.5%	0.1%	0.2%	0.4%
Net A2-WM	0.1%	0.5%	1.6%	0.1%	0.5%	1.7%	0.1%	0.5%	1.6%

Sources: Authors' calculations.

Appendix Table B1 (cont.): Annual damages in sensitivity tests

	2025	2055	2085	2025	2055	2085	2025	2055	2085
	Storm Surge Severity Decrease			Storm Surge Severity Increase			Storm Surge Frequency Decrease		
Total Damages (billions CAD2008)									
CC-LS	1.8	2.6	3.7	3.3	4.9	7.4	1.1	1.7	2.6
CC-WM	2.5	6.1	14.8	4.7	11.8	29.5	1.6	4.0	10.3
B1-LS	1.8	2.9	5.2	3.5	5.8	9.3	1.2	2.2	3.7
B1-WM	2.5	7.0	21.0	5.0	13.9	37.2	1.8	5.3	15.0
A2-LS	2.6	5.4	10.0	4.7	8.3	14.1	1.9	3.6	6.4
A2-WM	3.8	13.2	40.3	6.8	20.1	56.9	2.7	8.8	25.8
Net B1-LS	0.0	0.4	1.5	0.2	0.8	1.9	0.2	0.5	1.2
Net B1-WM	0.0	0.9	6.2	0.4	2.1	7.7	0.2	1.3	4.7
Net A2-LS	0.9	2.9	6.3	1.4	3.4	6.8	0.8	1.9	3.8
Net A2-WM	1.3	7.1	25.5	2.1	8.3	27.4	1.2	4.7	15.5
Damages as a share of each year's GDP									
CC-LS	0.1%	0.2%	0.3%	0.2%	0.3%	0.5%	0.1%	0.1%	0.2%
CC-WM	0.2%	0.4%	0.9%	0.3%	0.7%	1.8%	0.1%	0.2%	0.6%
B1-LS	0.1%	0.2%	0.4%	0.2%	0.4%	0.6%	0.1%	0.2%	0.3%
B1-WM	0.2%	0.4%	1.3%	0.3%	0.9%	2.3%	0.1%	0.3%	0.9%
A2-LS	0.2%	0.4%	0.7%	0.3%	0.6%	1.0%	0.1%	0.2%	0.4%
A2-WM	0.2%	0.8%	2.5%	0.4%	1.2%	3.5%	0.2%	0.5%	1.6%
Net B1-LS	0.0%	0.0%	0.1%	0.0%	0.1%	0.1%	0.0%	0.0%	0.1%
Net B1-WM	0.0%	0.1%	0.4%	0.0%	0.1%	0.5%	0.0%	0.1%	0.3%
Net A2-LS	0.1%	0.2%	0.4%	0.1%	0.2%	0.5%	0.1%	0.1%	0.3%
Net A2-WM	0.1%	0.4%	1.6%	0.1%	0.5%	1.7%	0.1%	0.3%	1.0%

	Storm Surge Frequency Increase			Lower Interval			Upper Interval		
Total Damages (billions CAD2008)									
CC-LS	3.0	4.5	6.8	0.9	1.2	1.8	4.3	6.5	9.9
CC-WM	4.3	10.9	27.4	1.2	2.9	7.1	6.1	15.7	39.7
B1-LS	3.3	5.6	9.1	0.9	1.3	2.1	4.6	7.8	12.8
B1-WM	4.7	13.4	36.6	1.2	3.0	8.3	6.7	18.8	51.4
A2-LS	4.6	8.4	14.4	1.3	2.6	4.8	6.0	10.9	18.8
A2-WM	6.7	20.3	58.1	1.8	6.3	19.5	8.8	26.2	75.9
Net B1-LS	0.3	1.0	2.3	0.0	0.0	0.3	0.4	1.3	2.9
Net B1-WM	0.4	2.5	9.2	0.0	0.1	1.2	0.6	3.1	11.7
Net A2-LS	1.6	3.9	7.6	0.4	1.4	3.0	1.8	4.3	8.9
Net A2-WM	2.4	9.4	30.6	0.6	3.4	12.4	2.6	10.5	36.2
Damages as a share of each year's GDP									
CC-LS	0.2%	0.3%	0.5%	0.1%	0.1%	0.1%	0.3%	0.4%	0.7%
CC-WM	0.3%	0.7%	1.7%	0.1%	0.2%	0.4%	0.4%	1.0%	2.4%
B1-LS	0.2%	0.4%	0.6%	0.1%	0.1%	0.1%	0.3%	0.5%	0.9%
B1-WM	0.3%	0.8%	2.3%	0.1%	0.2%	0.5%	0.4%	1.2%	3.2%
A2-LS	0.3%	0.6%	1.0%	0.1%	0.2%	0.3%	0.4%	0.7%	1.3%
A2-WM	0.4%	1.3%	3.6%	0.1%	0.4%	1.2%	0.5%	1.6%	4.7%
Net B1-LS	0.0%	0.1%	0.2%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%
Net B1-WM	0.0%	0.2%	0.6%	0.0%	0.0%	0.1%	0.0%	0.2%	0.7%
Net A2-LS	0.1%	0.3%	0.5%	0.0%	0.1%	0.2%	0.1%	0.3%	0.6%
Net A2-WM	0.1%	0.6%	1.9%	0.0%	0.2%	0.8%	0.2%	0.6%	2.2%

Sources: Authors' calculations.

Appendix Table B2: Cumulative damages in sensitivity tests

	CC-LS	CC-WM	B1-LS	B1-WM	A2-LS	A2-WM	Net B1-LS	Net B1-WM	Net A2-LS	Net A2-WM
Base Model										
Absolute damages (billions CAD2008)										
Discount Rate										
3 percent	91.7	197.4	109.3	244.9	165.2	379.6	17.6	47.5	73.5	182.2
0 percent	336.8	999.0	429.4	1,313.3	675.8	2,103.4	92.6	314.3	339.0	1,104.5
Damage as a share of 2011 GDP										
Discount Rate										
3 percent	6.3%	12.2%	7.5%	15.1%	11.3%	23.4%	1.2%	2.9%	5.0%	11.2%
0 percent	23.0%	61.6%	29.3%	81.0%	46.2%	129.7%	6.3%	19.4%	23.2%	68.1%
SLR Rate Increase										
Absolute damages										
Discount Rate										
3 percent	91.7	197.4	115.4	261.1	171.7	397.0	23.7	63.7	80.0	199.6
0 percent	336.8	999.0	460.9	1,419.9	709.4	2,217.5	124.1	420.9	372.6	1,218.6
Damage as a share of 2011 GDP										
Discount Rate										
3 percent	6.3%	12.2%	7.9%	16.1%	11.7%	24.5%	1.6%	3.9%	5.5%	12.3%
0 percent	23.0%	61.6%	31.5%	87.5%	48.5%	136.7%	8.5%	25.9%	25.5%	75.1%
SLR Rate Decrease										
Absolute damages										
Discount Rate										
3 percent	91.7	197.4	103.2	228.3	158.6	362.0	11.4	30.9	66.9	164.6
0 percent	336.8	999.0	397.0	1,203.4	641.7	1,987.8	60.2	204.5	304.9	988.9
Damage as a share of 2011 GDP										
Discount Rate										
3 percent	6.3%	12.2%	7.0%	14.1%	10.8%	22.3%	0.8%	1.9%	4.6%	10.1%
0 percent	23.0%	61.6%	27.1%	74.2%	43.8%	122.5%	4.1%	12.6%	20.8%	61.0%
Discount Rate Decrease										
Absolute damages										
Discount Rate										
1 percent	203.8	546.5	254.3	706.7	395.2	1,121.8	50.4	160.2	191.4	575.3
0 percent	336.8	999.0	429.4	1,313.3	675.8	2,103.4	92.6	314.3	339.0	1,104.5
Damage as a share of 2011 GDP										
Discount Rate										
1 percent	13.9%	33.7%	17.4%	43.6%	27.0%	69.2%	3.4%	9.9%	13.1%	35.5%
0 percent	23.0%	61.6%	29.3%	81.0%	46.2%	129.7%	6.3%	19.4%	23.2%	68.1%
RSLR Rates Decrease										
Absolute damages										
Discount Rate										
3 percent	88.8	189.5	106.5	237.3	162.9	373.3	17.7	47.8	74.1	183.8
0 percent	321.3	947.1	414.5	1,263.3	663.3	2,060.2	93.1	316.2	342.0	1,113.1
Damage as a share of 2011 GDP										
Discount Rate										
3 percent	6.1%	11.7%	7.3%	14.6%	11.1%	23.0%	1.2%	2.9%	5.1%	11.3%
0 percent	22.0%	58.4%	28.3%	77.9%	45.3%	127.0%	6.4%	19.5%	23.4%	68.6%

Sources: Authors' calculations.

Appendix Table B2 (cont.): Cumulative damages in sensitivity tests

	CC-LS	CC-WM	B1-LS	B1-WM	A2-LS	A2-WM	Net B1-LS	Net B1-WM	Net A2-LS	Net A2-WM
RSLR Rates Increase										
Absolute damages										
Discount Rate										
3 percent	94.8	205.6	112.2	252.4	167.7	386.6	17.4	46.9	72.9	181.0
0 percent	352.9	1,053.0	444.1	1,362.7	689.6	2,152.0	91.2	309.7	336.7	1,099.0
Damage as a share of 2011 GDP										
Discount Rate										
3 percent	6.5%	12.7%	7.7%	15.6%	11.5%	23.8%	1.2%	2.9%	5.0%	11.2%
0 percent	24.1%	64.9%	30.3%	84.0%	47.1%	132.7%	6.2%	19.1%	23.0%	67.8%
Storm Surge Severity Decrease										
Absolute damages										
Discount Rate										
3 percent	67.5	142.6	75.0	168.2	125.3	297.6	7.5	25.7	57.8	155.0
0 percent	240.2	701.6	296.9	916.9	540.9	1,717.9	56.6	215.3	300.6	1,016.4
Damage as a share of 2011 GDP										
Discount Rate										
3 percent	4.6%	8.8%	5.1%	10.4%	8.6%	18.3%	0.5%	1.6%	4.0%	9.6%
0 percent	16.4%	43.3%	20.3%	56.5%	37.0%	105.9%	3.9%	13.3%	20.5%	62.7%
Storm Surge Severity Increase										
Absolute damages										
Discount Rate										
3 percent	127.8	274.1	144.8	320.0	203.3	461.2	17.0	45.9	75.5	187.1
0 percent	466.1	1,378.4	555.7	1,683.3	814.1	2,512.9	89.6	304.8	348.0	1,134.4
Damage as a share of 2011 GDP										
Discount Rate										
3 percent	8.7%	16.9%	9.9%	19.7%	13.9%	28.4%	1.2%	2.8%	5.2%	11.5%
0 percent	31.8%	85.0%	38.0%	103.8%	55.6%	154.9%	6.1%	18.8%	23.8%	69.9%
Storm Surge Frequency Decrease										
Absolute damages										
Discount Rate										
3 percent	43.4	93.6	53.8	121.6	86.0	199.5	10.4	28.0	42.6	105.9
0 percent	160.2	476.0	214.8	661.2	357.4	1,119.3	54.6	185.2	197.2	643.4
Damage as a share of 2011 GDP										
Discount Rate										
3 percent	3.0%	5.8%	3.7%	7.5%	5.9%	12.3%	0.7%	1.7%	2.9%	6.5%
0 percent	10.9%	29.3%	14.7%	40.8%	24.4%	69.0%	3.7%	11.4%	13.5%	39.7%
Storm Surge Frequency Increase										
Absolute damages										
Discount Rate										
3 percent	117.8	253.2	138.1	308.1	203.2	464.3	20.3	54.9	85.5	211.1
0 percent	431.5	1,278.8	538.4	1,641.8	823.3	2,552.3	106.9	363.0	391.8	1,273.6
Damage as a share of 2011 GDP										
Discount Rate										
3 percent	8.0%	15.6%	9.4%	19.0%	13.9%	28.6%	1.4%	3.4%	5.8%	13.0%
0 percent	29.5%	78.8%	36.8%	101.2%	56.3%	157.3%	7.3%	22.4%	26.8%	78.5%

Sources: Authors' calculations.

Appendix Table B2 (cont.): Cumulative damages in sensitivity tests

	CC-LS	CC-WM	B1-LS	B1-WM	A2-LS	A2-WM	Net B1-LS	Net B1-WM	Net A2-LS	Net A2-WM
Lower Interval										
Absolute damages										
Discount Rate										
3 percent	32.7	68.9	33.9	72.9	60.4	143.4	1.1	4.0	27.6	74.4
0 percent	115.8	337.5	125.2	375.1	260.7	828.3	9.3	37.6	144.9	490.8
Damage as a share of 2011 GDP										
Discount Rate										
3 percent	2.2%	4.2%	2.3%	4.5%	4.1%	8.8%	0.1%	0.2%	1.9%	4.6%
0 percent	7.9%	20.8%	8.6%	23.1%	17.8%	51.1%	0.6%	2.3%	9.9%	30.3%
Upper Interval										
Absolute damages										
Discount Rate										
3 percent	169.0	364.3	194.8	433.9	264.9	604.3	25.8	69.6	95.9	240.0
0 percent	621.6	1,846.4	757.3	2,307.7	1,071.0	3,325.8	135.6	461.3	449.4	1,479.4
Damage as a share of 2011 GDP										
Discount Rate										
3 percent	11.5%	22.5%	13.3%	26.8%	18.1%	37.3%	1.8%	4.3%	6.6%	14.8%
0 percent	42.5%	113.8%	51.7%	142.3%	73.2%	205.0%	9.3%	28.4%	30.7%	91.2%

Sources: Authors' calculations.

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