Climate-Induced Sea-Level Rise and Storm Surge in Canada: Economic Impacts and Adaptation

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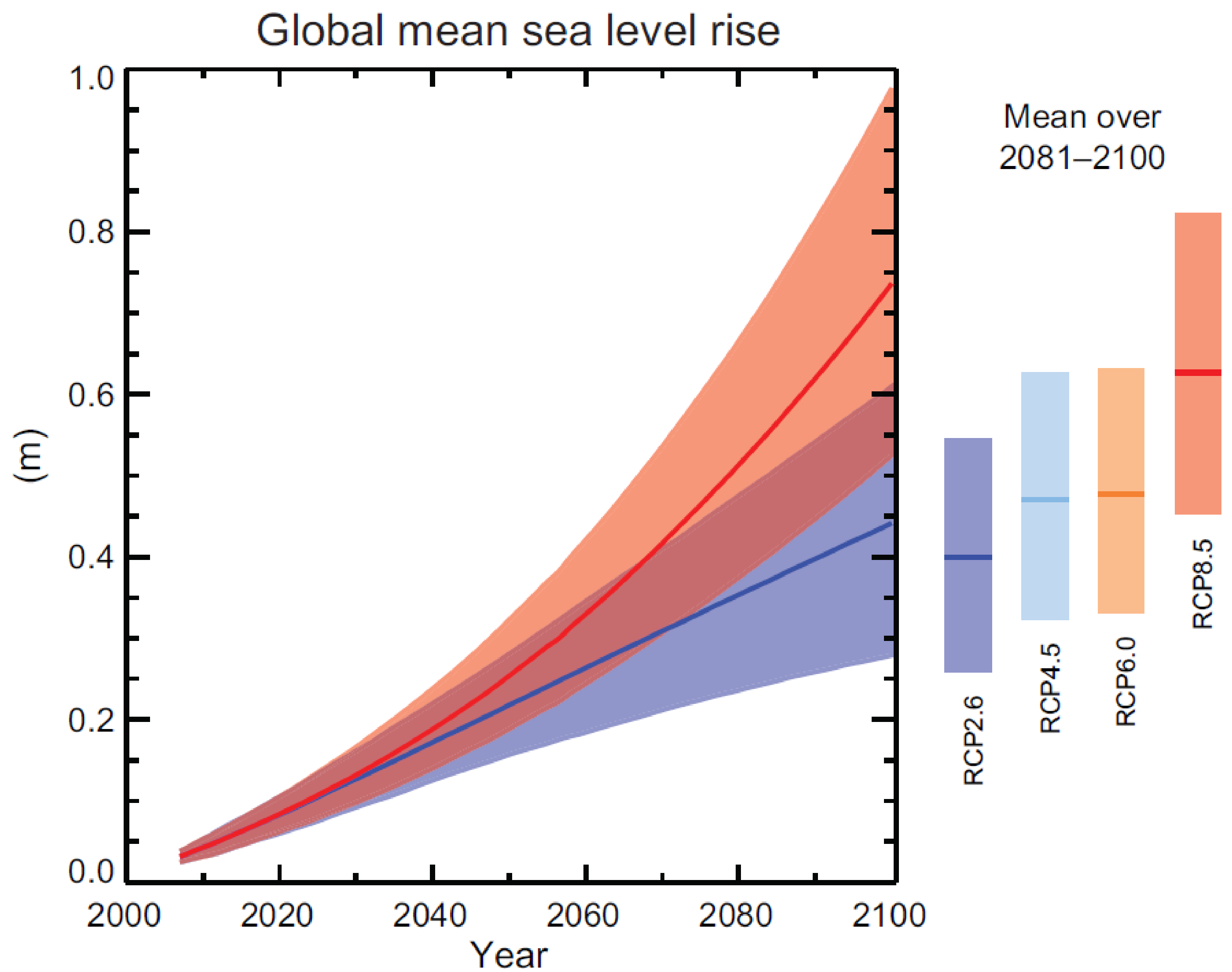
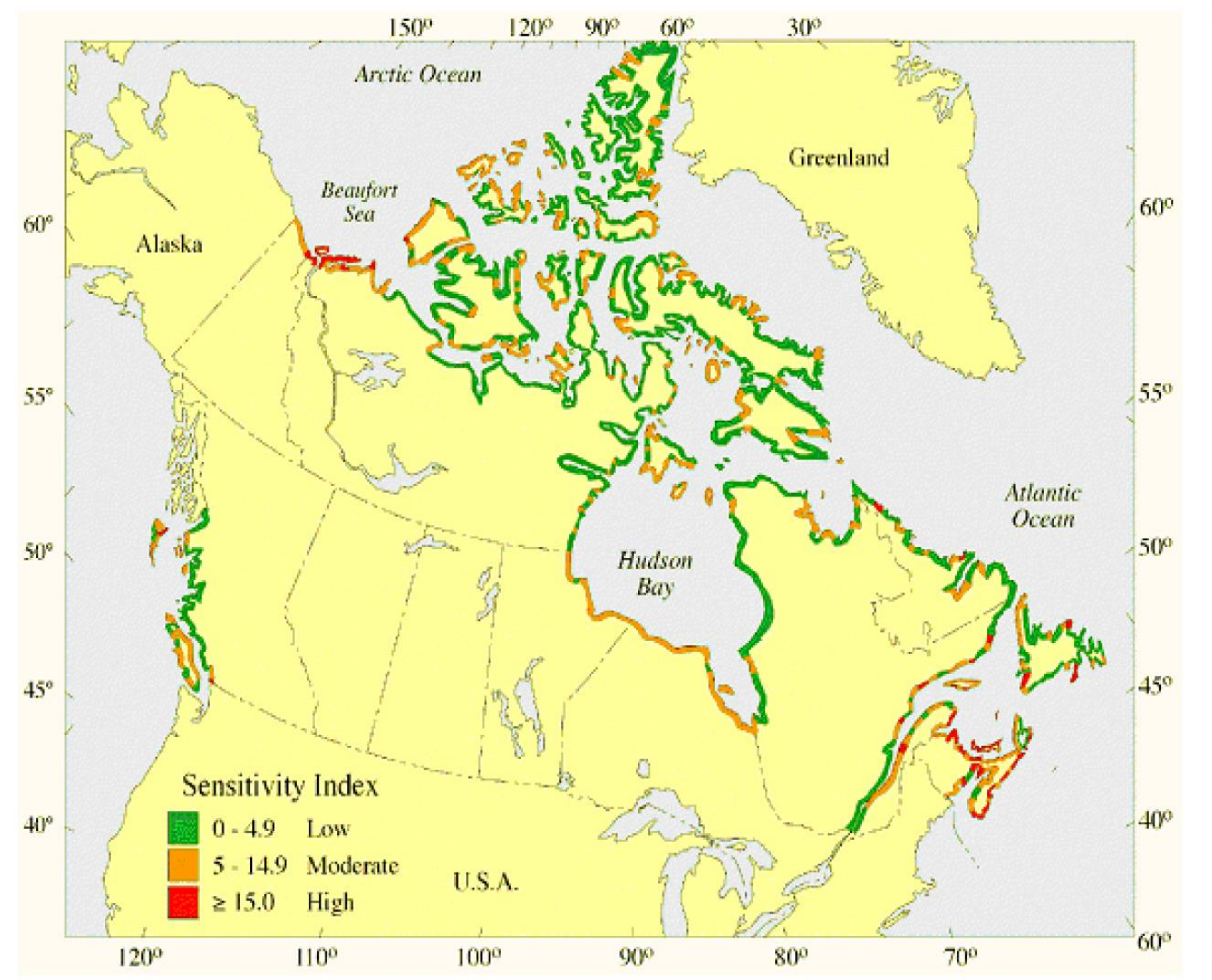
1. Introduction

- Increased GHG's in the atmosphere may increase global temperature by 2 °C or more by 2100

- Effects on the natural system may include:
  - Sea-level rise (SLR) and land loss
  - Damages from storm surge
  - Agricultural production changes
  - Biodiversity changes

IPCC 2013


Global mean sea level rise
1.0
0.8
0.6
0.4
0.2
0.0
(m)
2000
2020
2040
2060
2080
2100
Year
Mean over
2081–2100
RCP2.6
RCP4.5
RCP6.0
RCP8.5


150°
120°
90°
60°
30°
Arctic Ocean
Greenland
Beaufort Sea
Alaska
60°
55°
50°
45°
40°
Atlantic Ocean
Hudson Bay
Sensitivity Index
0 - 4.9 Low
5 - 14.9 Moderate
≥ 15.0 High
U.S.A.
120°
110°
100°
90°
80°
70°
60°

The Big Question

- Should we act now (and incur costs) to decrease future damages? How should we act?

- Requires a multidisciplinary approach
  - Likely climate outcomes due to GHG emissions
  - Physical impacts of climate outcomes
  - Costs of impacts, as well as costs of mitigation or adaptation

Role of Economics

- ❖ Quantify climate impacts (future damages) and inform mitigation or adaptation policy
- ❖ Global models capture the (saved) global damages from climate as well as costs of mitigation
- ❖ A great deal of work is done at the regional level
  - Cost-benefit analysis of adaptation for at risk sites
  - CGE models capture impacts for entire regions

Goal of Today's Talk

- ❖ Discuss the net benefits of adaptation, focusing on the impacts of SLR and storm surge in Canada

- ❖ Demonstrate how economic research may inform climate policy, through the use of two complementary studies/approaches

  - Computable General Equilibrium (CGE) impacts of SLR across Canadian provinces

  - Cost Benefit Analysis of adaptation options at six sites in Atlantic Canada

2. CGE Modeling

- CGE models use observed data to describe the economy, and are often used to determine economy-wide impacts due to changes in policy or exogenous variables
  - Model consumer and producer behaviour in multiple sectors for commodities and factors of production
  - Specify a general equilibrium: allow prices to adjust so supply and demand are equal (for commodities and factors of production)
  - Run shocks to various sectors, capturing direct impacts plus indirect impacts in other sectors

Modeling Climate Scenarios

- For each of 7 coastal provinces, we build a dynamic CGE model that includes 21 sectors and solves a general equilibrium based on 2009 data
- We shock land and capital based on climate impacts (SLR/surge) for various climate scenarios, and re-run the model from 2009-2054 to compare results
- Shocks: from Stanton et al. (2010), who estimate physical impacts and direct costs of SLR and storm surge

Direct annual damage costs due to sea level rise and storm surge (Mill 2008C$; using 2055 annual values)

	Dwellings (capital) damage	Forest & Ag. land damages	**Protection Costs**
BC	2,215	0.40	30
Terr.	79	6.06	15,149
QC	271	4.24	102
NB	538	0.52	622
NS	308	0.14	462
PEI	60	0.14	218
NL	52	0.24	195

Data: Protection

- We compare ***no protection*** (economic damages only) to ***full protection*** (no economic damages)

- Protection costs are modeled as follows:
  - Shaw et al. (1998) find that 3% (roughly 6000 km) of coastline is at risk
  - Darwin and Tol (2002) state that protection to mitigate against climate will cost $2.8 million per km in Canada

Cumulative CGE Impacts Relative to Baseline ($Bill)

		Climate Damages	Protect
BC	GDP	19.86	0.69
	CV	1.07	0.09
Terr	GDP	2.20	16.60
	CV	2.44	22.37
QC	GDP	11.17	0.87
	CV	8.70	0.68
NB	GDP	8.94	1.85
	CV	-8.97	-2.14
NS	GDP	3.98	1.11
	CV	1.08	0.29
PEI	GDP	0.92	0.66
	CV	0.45	0.31
NL	GDP	-2.38	0.44
	CV	-0.49	-0.10

Discussion

- We estimate impacts in the range of $4.6-26 Billion in present value welfare, and $55-109 Billion in present value GDP.
- The estimated impacts can help to inform policy
  - In all cases other than the Territories, policy to protect against climate impacts is warranted
- Complete protection at the provincial level may be infeasible; CBA can help inform specific adaptation options at vulnerable sites…

3. Cost Benefit Analysis (CBA)

- **CBA** is a relatively simple tool that compares the benefits and costs of a program or policy
- Often done at the site level, and contains detail for policy
- In the case of climate change and adaptation, we compare the **benefits** of reduced climate damages to the **costs** of adaptation
  - Direct costs, but more detailed adaptation options

CBA of Adaptation in Atlantic Canada

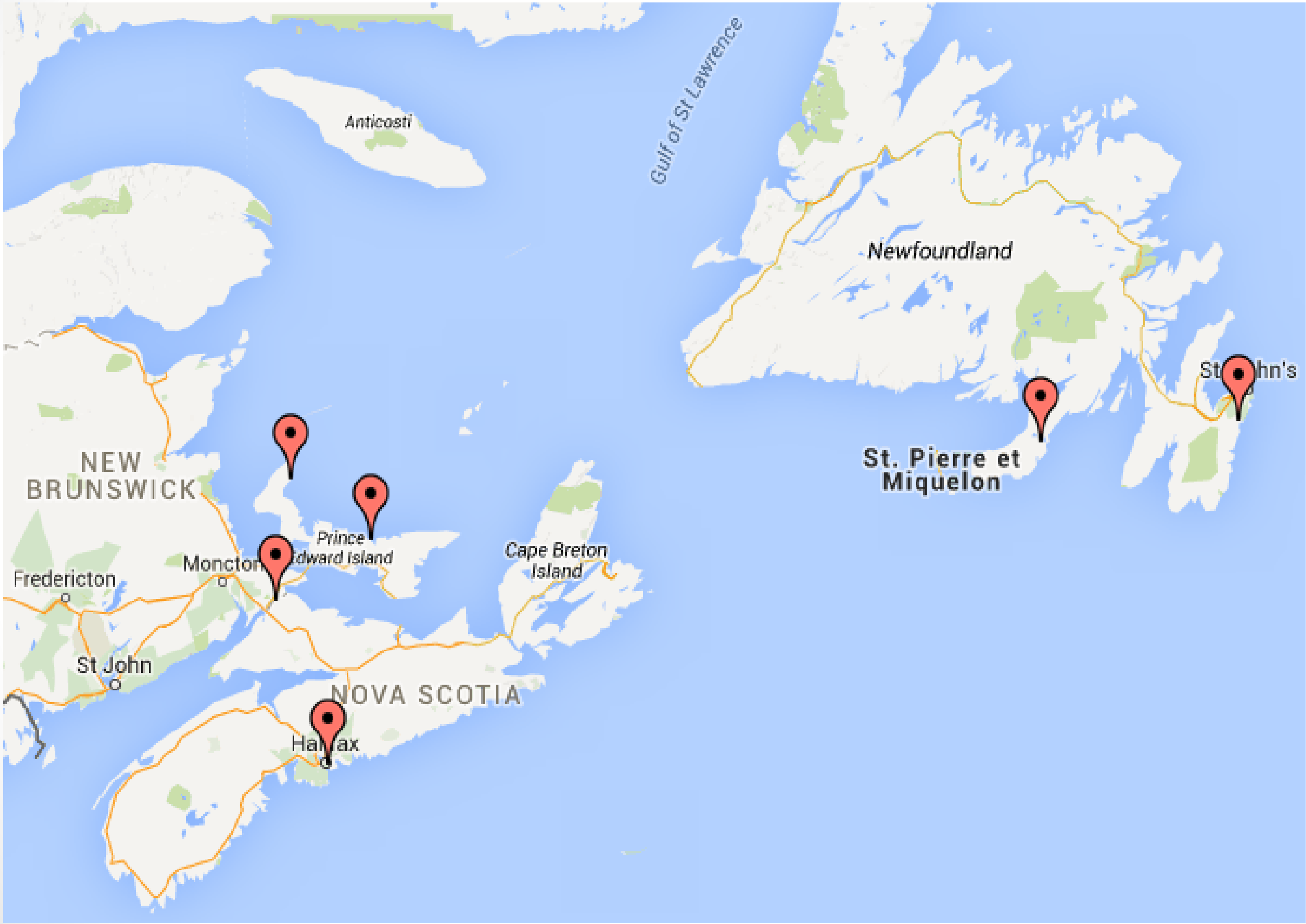
- We focus on adaptation options to mitigate impacts from SLR and storm surge at six sites
  - Focus is on physical infrastructure (unlike CGE work)

- Climate damages are based on most likely climate outcome (RCP 8.5), including:
  - Metres of inundation for coastal flood levels:
    1-10, 1-25, 1-50 and 1-100 return periods
  - Data for the years 2010, 2040, 2060, 2070
  - Map climate scenarios to infrastructure at risk (GIS) and estimate **annual** expected damages

Costs and Benefits of Adaptation

- We calculate **expected** climate damages
  - Expected annual damages (from all storms) for each type of infrastructure in each year, summed from 2015-2065
- Compare **Benefits** (avoided climate damages) to **Costs** (implementation of adaptation option) using net present value
  - Adaptation options are site specific and include raising dikes, building sea walls and retreating
- Adaptation option with highest NPV is most desirable

CBA of Adaptation in Atlantic Canada



Example: Chignecto Isthmus

Physical Infrastructure

- Roads, rail, dykes and transmission lines

Trade and Traffic delays

- Value added approach following Yevdokimov (2012)

2015-2065 Costs ($Millions, 4% Discount)

	Without Trade
NB Dykes	16.9
NS Dykes	10.4
NB Rail	51.9
NS Rail	13.6
NS Road & Ramp	12.5
NB Road & Ramp	19.7
Roads: Value Added Trade	1.5
Rail: Value Added Trade	0.4
Traffic	1.3
NB Transmission	0.2
NS Transmission	2.4
Trade	*0*
Total Costs	**130.8**

2015-2065 Costs ($Millions, 4% Discount)

	Without Trade	With Trade
NB Dykes	16.9	16.9
NS Dykes	10.4	10.4
NB Rail	51.9	51.9
NS Rail	13.6	13.6
NS Road & Ramp	12.5	12.5
NB Road & Ramp	19.7	19.7
Roads: Value Added Trade	1.5	0
Rail: Value Added Trade	0.4	0
Traffic	1.3	1.3
NB Transmission	0.2	0.2
NS Transmission	2.4	2.4
Trade	*0*	*329.7*
Total Costs	**130.8**	**458.6**

	Adaptation Option	$Millions
1	Agriculture dykes, existing location	$225
2	Agriculture dykes, shortened	$212
3	Engineered dykes, existing location	$118
4	Engineered dykes, shortened, public infrastructure only	$138
5	Engineered dykes, shortened, protect all infrastructure	$97
6	Re-route TCH (50 km)	$386

No Trade (4% Discount)

	1	2	3	4	5	6
NPV in $Millions	119.0	106.2	12.3	32.1	9.0	279.9
Benefit-Cost Ratio	0.45	0.47	0.86	0.73	1.05	0.26

With Trade (4% Discount)

	1	2	3	4	5	6
NPV in $Millions	73.6	86.5	180.3	160.6	201.7	87.2
Benefit-Cost Ratio	1.20	1.26	1.91	1.73	2.17	0.77

No Trade (4% Discount)

	1	2	3	4	5	6
NPV in $Millions	119.0	106.2	12.3	32.1	9.0	279.9
Benefit-Cost Ratio	0.45	0.47	0.86	0.73	1.05	0.26

With Trade (4% Discount)

	1	2	3	4	5	6
NPV in $Millions	73.6	86.5	180.3	160.6	201.7	87.2
Benefit-Cost Ratio	1.20	1.26	1.91	1.73	2.17	0.77

Option 5: Engineered dykes, shortened, protect all infrastructure

Conclusion

- These studies demonstrate different ways in which economics can be used to inform climate change policy

- There isn't necessarily a "one size fits all" approach to adaptation, which contrasts the broad policy approaches in mitigation

- Through the use of a multi-disciplinary approach, we observe that impacts of climate change in Canada may be significant, and adaptation may be warranted in at-risk sites