Climate Change Cost-Benefit Analysis for Public Infrastructure in Canada

Final Technical Report

2026-03-20

CA0055522.2661

Document distribution

Canadian Climate Institute

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2025-03-20

CA0055522.2661

Prepared for

Canadian Climate Institute

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Suggested citation:

WSP Canada. 2026. *Climate Change Cost-Benefit Analysis for Public Infrastructure in Canada: Technical Report.* Montréal, QC: WSP Canada Inc.

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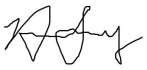
	Annabelle Lamy, **MSc** Advisor, ESG & Climate Advisory	2026-03-20	
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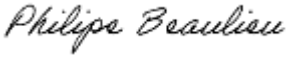
	Philipe Latulippe Beaulieu Economist, Ontario Advisory Services	2026-03-20	
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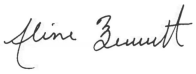
Approved by:	**Aline Bennett, MASc, PMP** Senior Manager, Climate Risk & Resilience	2026-03-20	

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Abbreviations and Glossary

Abbreviations

AAL	Average Annual Loss
CBA	Cost-benefit Analysis
CPIS	Core Public Infrastructure Survey
CRV	Current Replacement Value
DEM	Digital Elevation Model
FAO	Financial Accountability Office of Ontario
FSA	Forward Sortation Area (postal code region)
GCM	Global Climate Model
IPCC	Intergovernmental Panel on Climate Change
O&M	Operations and Maintenance
SSP	Shared Socioeconomic Pathway
USL	Useful Service Life

Glossary of Terms

Adaptation	Adjustments in systems or practices to moderate or avoid harm from climate change impacts. In infrastructure, this includes upgrades, retrofits, or new designs to withstand future climate conditions.
Alpha Coefficient (αi,c)	A metric used to quantify the sensitivity of costs to climate variation for a given infrastructure component.
Asset Deterioration Model	A quantitative model that estimates the decline in infrastructure asset condition over time, factoring in both age and climate impacts, to inform maintenance and replacement strategies.
Average Annual Loss (AAL)	The expected value of losses per year, averaged over a long period, due to hazards such as flooding.
CatIQ	Catastrophe Indices and Quantification Inc., a Canadian platform providing standardized data on natural and human-made catastrophes.
Climate Hazard	A climate-related event or trend (e.g., increased temperature, precipitation, flooding, wildfire) that poses risks to infrastructure.
Climate Indicator	A variable (e.g., annual total precipitation, maximum daily temperature) used to track and project climate change impacts.
Climate Representative Regions	Groupings of municipalities or areas with similar climate characteristics, used to simplify climate impact modeling.

Cost-Benefit Analysis (CBA)	A systematic approach to estimating the strengths and weaknesses of alternatives used to determine options that provide the best approach to achieving benefits while preserving savings. In this context, it refers to evaluating the costs and benefits of climate adaptation for public infrastructure.
Current Replacement Value (CRV)	The estimated cost to replace an asset at current prices, used for budgeting and risk assessment.
Digital Elevation Model (DEM)	A 3D representation of a terrain's surface, used in flood and climate modeling.
Forward Sortation Area (FSA)	The first three characters of a Canadian postal code, used for regional analysis.
Global Climate Model (GCM)	Mathematical models that simulate the Earth's climate system, used for projecting future climate scenarios.
Industry Exposure Database (IED)	Dataset of Canadian property insurance exposure, used for risk and loss modeling.
Köppen-Geiger Classification	A widely used climate classification system based on temperature and precipitation patterns.
No Adaptation	Scenario where assets are not adapted at replacement, assuming 100% of infrastructure is not resilient to climate change.
Operations and Maintenance (O&M)	Ongoing activities required to keep infrastructure assets in a state of good repair.
Physical Condition Rating	A classification of asset condition (e.g., very poor, poor, fair, good, very good, unknown) used in asset management.
Proactive Adaptation	Strategy where assets are adapted at the first available opportunity (e.g., during major rehabilitation or replacement), rather than waiting for failure or end-of-life.
Reactive Adaptation	Strategy where assets are only adapted at the time of replacement, leading to a gradual increase in adapted assets over time.
Benefit Cost Ratio (BCR)	A measure of the profitability of an investment, calculated as the ratio of net benefits to costs.
Shared Socioeconomic Pathway (SSP)	Scenarios of projected socioeconomic global changes up to 2100, used in climate modeling.
Useful Service Life (USL)	The expected period during which an asset is able to perform its intended function with some minor maintenance.

Executive Summary

Purpose of This Report

This report provides a transparent and detailed account of the methods, data sources, modelling framework, assumptions, and results that underpin Canadian Climate Institute's (CCI) national evaluation of climate-related infrastructure costs and adaptation pathways in Prepare or Repair: How climate proofing public infrastructure pays off (Ness, Carriere, & Gauer, 2026). By setting out the technical steps underlying the analysis, including the construction of the asset inventory, application of climate projections, deterioration modelling, and comparison of adaptation scenarios, this report enables readers to understand how the findings in Prepare or Repair were produced and how they relate to the structure and behaviour of the model.

Assessing infrastructure costs in the context of climate change is essential as the physical conditions that influence asset deterioration and performance are changing. Higher temperatures, more intense rainfall, and shifting environmental stressors alter the frequency of maintenance, rehabilitation, and replacement across infrastructure systems. Evaluating how these climate stressors interact with Canada's aged asset base helps clarify how long-term costs evolve under different climate futures and why adaptation timing significantly affects lifecycle outcomes. This technical assessment was produced to quantify those effects systematically.

Scope of the Analysis

The scope of this analysis reflects the elements that can be assessed consistently across Canada using available national datasets and deterioration-based modelling, defining the boundaries of what is included in the technical assessment that underpins the *Prepare or Repair* report.

- **Geographic Scope:** The study covers all provinces and territories in Canada, with assets grouped into climate-representative regions based on national climate projections. Results are reported at national, provincial/territorial, and asset-class levels.
- **Asset Classes:** Comprise roads, public buildings, wastewater systems, and stormwater systems. These are all asset types with complete, standardized national data from Statistics Canada's Core Public Infrastructure Survey. Energy and communications systems and specialized or community-level facilities were not included as national data or deterioration parameters were incomplete or inconsistent.
- **Climate Hazards:** The study focused on extreme heat and extreme rainfall. Flooding was also evaluated through a complementary high-level analysis of flood-protection investments.
- **Cost Factors:** Direct infrastructure lifecycle costs, including operations and maintenance, repair, rehabilitation, replacement, and adaptation-related capital costs, as well as direct flood-related

damages in the flood-protection assessment were included. Indirect economic and social impacts such as service disruptions, property damage, emergency response, and business interruption, were excluded.

- **Time Horizons:** Four periods consistent with national climate datasets were included: the historical baseline (1991–2020), near-term (2025–2040), mid-century (2041–2070), and end-century (2071–2100).

Analytical Framework

A national framework was applied that integrates infrastructure data, climate projections, and deterioration modelling.

- **Asset Inventory:** A national asset inventory was constructed using Statistics Canada's Canadian Public Infrastructure Survey (CPIS). Specific asset characteristics in the inventory include baseline attributes, age, condition, replacement value, and quantity, of each major infrastructure type. These attributes provide the baseline parameters used in the deterioration model and were used to determine baseline service life and intervention needs.
- **Climate Projections:** Future climate conditions were represented using statistically downscaled IPCC AR6 projections from ClimateData.ca under SSP1-2.6, SSP2-4.5, and SSP3-7.0. Projections for temperature and precipitation were applied to each climate-representative region to adjust deterioration rates. Results focus on outputs under SSP2-4.5.
- **Asset Deterioration Model:** A deterioration model estimates how assets age and when maintenance, rehabilitation, or replacement are required under a stable climate. Climate-adjusted deterioration is then overlaid to assess how heat and rainfall accelerate wear, shorten useful service life, and shift cost trajectories.
- **Adaptation Scenarios:** Four scenarios were modelled. These scenarios isolate the effect of adaptation timing on long-term outcomes:
  - Baseline – no climate change;
  - No Adaptation – assets remain built to historic standards under changing climate conditions;
  - Reactive Adaptation – assets upgraded only at replacement under changing climate conditions; and
  - Proactive Adaptation – assets upgraded at earliest feasible intervention (major rehabilitation or replacement) under changing climate conditions.
- **Aggregation and Reporting:** Results were aggregated to provincial, territorial, federal, and national levels using Current Replacement Value (CRV) based weightings, ensuring comparability across asset types and geographies.
- **Supplementary Modelling:** A complementary national-scale flood assessment was completed using CatIQ's historical insured-loss data and building-level flood-risk projections from the Canadian Climate

Institute. This analysis estimated baseline and future flood-related damages and evaluated the potential benefits of structural protection measures, providing high-level, nationally comparable insights that sit alongside, but are methodologically distinct from, the deterioration-based modelling.

Key Findings

The following key findings summarize the major insights from the modelling, highlighting how infrastructure costs evolve under a stable climate, how they change when climate impacts are included, and how different adaptation pathways affect long-term outcomes.

- **Under a stable climate, infrastructure costs remain substantial.** Even without climate change, Canada faces high and sustained lifecycle costs due to aging assets, accumulated maintenance gaps, and long replacement cycles. The stable-climate baseline reflects the significant investment required simply to keep existing systems in a state of good repair.
- **When climate change is incorporated, projected costs rise across all regions and asset classes.** Under a no-adaptation pathway, climate impacts increase annual infrastructure management costs by approximately $8.8B per year in the near-term, rising to $14.3B per year by mid-century and $19.4B per year by late century. Averaged over 2025–2100, this corresponds to $15.1B per year above stable-climate conditions.
- **Adaptation is cost-effective across all major asset classes, with timing being a decisive factor.** Over 2025–2100, average annual climate-related costs fall from $15.1B with no adaptation to $10.6B under reactive adaptation, and further to approximately $6.5B under proactive adaptation. Proactive adaptation delivers the strongest fiscal performance by reducing long-term costs and moderating mid-century cost escalation.
- **Asset-class differences reinforce the value of early action.** Roads, stormwater, and wastewater systems, where climate-driven deterioration is most pronounced, show particularly strong cost-effectiveness when upgraded proactively. Buildings and other long-lived assets also benefit, though timing plays a larger role due to their longer renewal cycles.
- **Modelled results are conservative, as only direct infrastructure costs are included.** Broader economic impacts such as service disruptions, property damage, business interruption, and emergency response are excluded from the modelling. Real-world benefits of adaptation would therefore be larger than the results presented here.

Limitations

The results presented in this report should be interpreted together with the following limitations related to data availability, hazard coverage, modelling assumptions, and uncertainty in future climate conditions.

- **Asset data gaps** in CPIS required generalized assumptions for asset age, condition, and service life. As a result, the modelling tends to produce conservative estimates for asset groups that may be in poorer-than-average condition.

- **Limited hazard coverage** means wildfire, permafrost thaw, drought, and coastal erosion were excluded due to the complexity and spatial uncertainty associated with assessing their impacts, which may understate long-term climate pressures.
- **Flood modelling is high-level** and does not replace detailed hydrological or hydraulic studies. Results reflect national comparability rather than local precision.
- **Climate projection uncertainty**, particularly for extreme rainfall, introduces a wide range of possible outcomes not fully captured by median projections. For instance, in some climate-representative regions, high-end CMIP6 projections indicate extreme rainfall intensities increasing at nearly twice the rate of the median estimate, while low-end projections show minimal change.
- **Simplified deterioration modelling** cannot fully represent engineering complexity or interdependencies between systems (e.g., stormwater failures affecting roads), contributing to conservative cost estimates. In addition, limited research on how individual climate-change metrics translate into aggregated lifecycle costs, particularly for asset-level modifications, means some climate–cost relationships cannot be fully captured, adding further uncertainty to long-term results.
- **No fiscal or behavioural constraints** are modelled; real-world underinvestment or deferred maintenance would likely increase costs beyond modelled values.

How to Read This Report

This technical report provides the methodological foundation for the Canadian Climate Institute's *Prepare or Repair* analysis. It documents the underlying datasets, modelling assumptions, analytical steps, and scenario design used to estimate how climate change influences long-term lifecycle costs for Canada's public infrastructure. The report proceeds from context, to methods, to results:

- **Section 1** outlines project purpose, and scope.
- **Section 2** describes the analytical framework, asset inventory, climate projections, deterioration modelling, adaptation scenarios, and limitations.
- **Section 3** presents modelling outputs across baseline, climate-impacted, and adaptation pathways.

Appendices provide additional technical details on data processing and model parameters.

Readers seeking high-level findings and policy interpretation should refer to the Canadian Climate Institute's *Prepare or Repair* report (Ness, Carriere, & Gauer, 2026). This document is intended to be technical and support CCI's summary report.

1. Introduction

This technical report documents the data sources, modelling framework, assumptions, and limitations that underpin the Canadian Climate Institute's report: *Prepare or Repair: How climate-proofing public infrastructure pays off* (Ness, Carriere, & Gauer, 2026). This report serves as the technical methodological companion to the CCI's public-facing report, providing transparency into how the national results were generated. The findings, parameters, and analytical choices described herein form the quantitative foundation for the Institute's national assessment of climate-related infrastructure costs and adaptation pathways.

1.1 Project Background

The Canadian Climate Institute (CCI) commissioned this study to establish a consistent national approach for understanding how climate change affects the life cycle costs of public infrastructure. Previous assessments were completed using different methods, datasets, and assumptions depending on the region or asset type. This inconsistency limited the ability to compare results across jurisdictions and made it difficult to understand the full national implications of climate driven asset deterioration.

This technical report addresses this jurisdictional comparison gap by constructing a national asset inventory, establishing a deterioration-modelling framework, and applying nationally consistent climate-hazard inputs. The objective was to create a technically sound platform for evaluating infrastructure deterioration under both stable and changing climate conditions, and for comparing adaptation pathways using clear, rule-based decision logic. This work focused specifically on the hazards that can be robustly integrated into a deterioration modelling framework at a national scale, specifically extreme heat and extreme rainfall. Flooding was addressed through a separate, high-level assessment consistent with available data and modelling feasibility.

A central motivation for this analysis was the need to rigorously assess how adaptation and the timing of adaptation affects long-term asset management costs. Infrastructure owners face decisions about when to upgrade assets to climate-resilient standards, and these choices have material implications for life-cycle performance.

The results of this technical analysis, covering baseline costs, climate-driven cost escalation, and the lifecycle cost differences of proactive versus reactive adaptation, form the quantitative foundation for the Canadian Climate Institute's *Prepare or Repair* report (Ness, Carriere, & Gauer, 2026). *Prepare or Repair* interprets and communicates the national-scale implications of the modelling; its findings, messages, and narratives are therefore grounded in the methods, datasets, and scenario results documented here.

1.2 Purpose

This report provides an up-to-date analysis of how climate change affects the life cycle costs of public infrastructure in Canada, and evaluates the costs and benefits associated with different adaptation strategies. For the purposes of this study, adaptation refers specifically to upgrading infrastructure assets to climate resilient standards, whether through early replacement, enhanced design, or the inclusion of resilience features during major rehabilitation. This definition allowed the modelling to focus on asset level measures that improve long term performance under projected climate conditions.

Within this study, adaptation can occur in two principal ways:

- **Reactive adaptation**, in which assets are upgraded to climate-resilient standards only at the point of replacement. Under this approach, adaptation occurs gradually over time as existing assets reach end-of-life, meaning many assets remain climate-vulnerable for extended periods.
- **Proactive adaptation**, in which assets are upgraded at the earliest feasible intervention, typically during major rehabilitation or renewal, rather than waiting until full replacement. This proactive approach accelerates the transition of the asset base to climate-resilient standards and reduces the duration of exposure to climate-driven deterioration.

These two approaches represent materially different adaptation pathways and formed a core focus of the analysis, enabling the study to assess how the timing of upgrades influenced long-term costs, risk exposure, and infrastructure performance.

The analytical approach drew on aspects of the Financial Accountability Office (FAO) of Ontario's *Costing Climate Change Impacts to Public Infrastructure* (CIPI) methodology, adapting selected components that were suitable for application on a national scale. Including elements of deterioration modelling, the use of climate sensitive cost parameters, and the general logic for comparing adaptation pathways. The broader framework was expanded and modified to reflect national datasets, regional diversity, and the requirements of a Canada-wide analysis.

The purpose of this technical study was to provide CCI with a consistent and transparent foundation for understanding how climate related deterioration, future hazard conditions, and different adaptation pathways influence long term infrastructure costs across the country. The results supplied the detailed quantitative evidence needed to support CCI's national scale research and conclusions.

1.3 Scope

The analysis focused on key categories of public infrastructure across all regions and jurisdictions in Canada, including roads, public buildings, stormwater systems, potable water, and wastewater systems. It assessed how climate risks and adaptation needs vary by asset type and geography, and it evaluated the implications of different adaptation pathways for long term infrastructure costs.

To define the scope of the study, the following boundaries were applied:

- **Geographic Scope** - The analysis was national in scope, covering all provinces and territories. Asset groupings are modelled at the provincial and territorial level, with federal assets aggregated nationally.
- **Asset Inventory** - The asset inventory was based on the publicly available datasets from Statistics Canada's CPIS, which provided national level information on the age, condition, replacement value, and quantity of major publicly owned infrastructure assets. The inventory included the asset classes that are comprehensively represented in these datasets, specifically roads, public buildings, wastewater systems, and stormwater systems, as these had consistent national coverage and sufficient data to support modelling. It excluded infrastructure types that do not have complete or nationally consistent data, such as energy and communications infrastructure, or specialized facility categories.
- **Climate Hazards** - The analysis was limited to temperature and precipitation projections, which were used to represent changes in heat and rainfall across Canada. As these datasets vary significantly across regions, the information was grouped into climate zones to allow for consistent national scale application. Flooding was also considered and was addressed through a separate high-level assessment using related loss and exposure data from CatIQ's Historical Catastrophe Database and Industry Exposure Database.
- **Cost Categories** - The analysis included operations and maintenance, repair, rehabilitation, replacement, and adaptation related capital costs. It did not include broader indirect or economy wide impacts such as productivity losses, social impacts, or insurance-related effects, as these require economic modelling that is outside the scope of this study. For these reasons, the results focused on direct infrastructure costs.
- **Time Horizons** - The analysis used consistent time periods aligned with available climate data and infrastructure life cycle modelling. These included a historical baseline (1991 to 2020), a near-term period (2011 to 2040), a mid-century period (2041 to 2070), and an end-of-century period (2071 to 2100). These horizons defined the temporal boundaries of the model and were used across all scenarios. In addition to these discrete periods, the analysis also reported results for the full 2025–2100 period. This long-run period is not an average of the near-, mid-, and end-of-century windows; rather, it represents a continuous calculation beginning in 2025 and extending through 2100.

2. Methodology

To assess and cost the impacts of climate change on public infrastructure in Canada, the study applied a structured, nationally consistent modelling framework designed to support CCI's analytical objectives. The approach combined a harmonized national asset inventory, standardized deterioration modelling, climate-informed adjustments, and clearly defined adaptation pathways. This structure ensured that modelling results reflected differences in assets and climate conditions rather than inconsistencies in data treatment or methodology, providing the transparent technical foundation for the national findings presented in Prepare or Repair (Ness, Carriere, & Gauer, 2026).

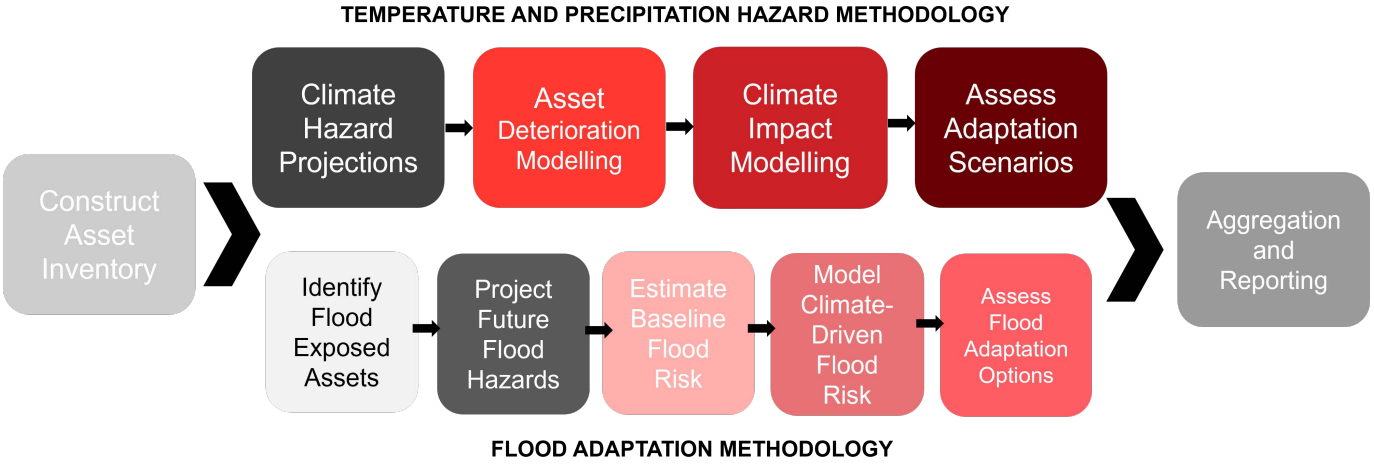

Figure 2.1: Overview of project methodology

The analysis follows the workflow illustrated in **Figure 2.1**, with each step corresponding to a specific component of the methodology:

- **Asset inventory (Section 2.2) –** Developed a national inventory of public infrastructure using Statistics Canada's Core Public Infrastructure Survey (CPIS), establishing the baseline characteristics and quantities of assets included in the model.
- **Baseline deterioration modelling (Section 2.3) -** Estimated service life, repair cycles, operations and maintenance needs, and replacement timing under stable climate conditions to generate the baseline cost profile for all asset classes.
- **Climate projection adjustment (Section 2.4) -** Applied projected changes in temperature and precipitation to adjust deterioration rates and cost trajectories, creating climate-influenced pathways that build on the baseline model.

- **Adaptation scenario decision rules (Section 2.5) -** Applied defined rules for the no adaptation, reactive adaptation, and proactive adaptation pathways to determine when climate-resilient upgrades occur and how these choices alter long-term cost outcomes.
- **Cost aggregation and outputs (Section 2.6) -** Aggregated results across asset groups, regions, and scenarios to produce national and provincial estimates of long-term infrastructure costs, climate-related impacts, and the benefits of different adaptation strategies.

A separate parallel analysis evaluated high-level flood-related damages using CatIQ's historical loss and exposure data was also completed, which is outlined in Section 2.8.

2.1 Constructing a National Asset Inventory

The analysis presented in this report relied on the CPIS from Statistics Canada as the foundation for developing a comprehensive national inventory of public infrastructure assets. The CPIS provides detailed, standardized data on infrastructure assets, including current replacement value, year of construction, physical condition, and asset quantities. This information is available for a wide range of asset types and includes geographic, ownership level, and municipal characteristics.

The CPIS data is made public through four main datasets:

- Estimated replacement value and physical condition rating: Provided the replacement value of assets and their associated condition state, allowing the model to link each asset class to both its current value and observed condition distribution.
- Inventory of core public infrastructure assets: Identified the number and length (in kilometers) of assets.
- Inventory distribution by physical condition rating: Presented the share of assets by condition.
- Inventory by year of completed construction: Detailed the number and proportion of assets by construction year.

These datasets, available for multiple years (2020 and 2022), each used their own terminology and classification structure. To combine them into a usable national database, WSP developed a harmonized nomenclature for asset groups, types, and subtypes. This harmonization was essential for merging datasets that otherwise varied in naming conventions and levels of detail.

Key steps in building the harmonized inventory included:

- Terminology Alignment: Standardizing asset classifications across all datasets for consistency.
- Data Integration: Combining financial metrics (replacement value) with physical measures (units, kilometers) into a master dataset, mapped across geography, asset type, ownership level, and reference year.

- Imputation Framework: Missing or incomplete information, such as physical condition or year of construction, was imputed using proportional allocation methods to distribute known totals across the required categories in a consistent manner.

Where data gaps existed, WSP identified opportunities to supplement the inventory using internal resources or partner data as needed.

Beyond serving as a descriptive national profile, the infrastructure inventory provided the core analytical foundation for the entire modelling framework. It anchored the deterioration model by defining the baseline characteristics of each asset group, including age distribution, condition, replacement value, and physical extent, which determined how each asset was expected to perform under stable climate conditions. These baseline characteristics drove estimates of useful service life, repair cycles, operations and maintenance needs, and replacement timing. All subsequent modelling steps, including the application of climate adjustments and adaptation scenario rules, build directly from this inventory. The asset inventory therefore functioned not only as an input dataset, but as the structural backbone of the analysis, shaping how climate stressors and adaptation decisions translated into long-term cost projections.

2.2 Selecting and Defining Climate Change Hazards

This analysis focused on the three climate hazards most relevant to Canadian public infrastructure: increased temperatures, increased rainfall, and flooding (including coastal flooding). These hazards were selected because they have clear and well documented relationships to how the infrastructure types in this study, including roads, public buildings, stormwater systems, and wastewater systems, deteriorate over time.

Increased temperatures affect material performance across these asset classes by accelerating processes such as asphalt softening leading to distresses such as shoving and rutting in roadways, thermal expansion and fatigue in building components, and increased stress on mechanical and electrical systems in public buildings. Higher temperatures can also increase corrosion rates in stormwater and wastewater systems, contributing to more frequent maintenance needs and shortened service lives.

Increased rainfall affects infrastructure performance primarily through greater moisture loading, more frequent saturation cycles, and higher hydraulic demands. Pavement structures experience weakened subgrade strength under persistent or extreme moisture, leading to cracking and premature rehabilitation. Public buildings face increased risks of envelope moisture intrusion and accelerated degradation of cladding and roofing systems. Stormwater and wastewater systems are directly impacted by higher inflows and infiltration, which can overwhelm capacity, increase wear on pipes and treatment facilities and can shorten the expected service life of key components.

For flooding, including both riverine and coastal flooding, WSP leveraged detailed flood risk and damage data from CCI's *Close to Home* report (Ness et al., 2025). This approach provided high-level estimates of flood-related impacts on infrastructure that complement the temperature- and rainfall-driven deterioration modelling. Flood modelling was handled separately due to the distinct data sources and analytical methods required; more information is provided in Section 2.8.

Other climate hazards, such as freeze–thaw cycles, permafrost thaw, wildfire, coastal erosion, and drought, are also relevant to public infrastructure. These were excluded as the modelling approach and available national datasets did not support consistent, Canada-wide estimates for these hazards. Their exclusion reflects project scope and data limitations rather than their overall importance.

The following section outlines the climate projection methodology for temperature and precipitation, including the selection of climate indicators, modelling approaches, and integration of hazard data into the asset deterioration analysis.

2.2.1 Representing Future Climate Conditions

Future climate is represented in this report using climate projections based on the Sixth Assessment Report (AR6; IPCC 2021), which represents the latest set of projections from the Intergovernmental Panel on Climate Change (IPCC). Future climate is projected using Global Climate Models (GCMs) that involve the mathematical representation of global land, sea and atmosphere interactions over a long period of time.

The data used in this report was obtained from ClimateData.ca (2025). The data is comprised of AR6 GCM outputs, which are statistically downscaled using n-dimensional Multivariate Bias Correction (MBCn) provided by the Pacific Climate Impacts Consortium (PCIC) to correct for systematic biases in precipitation and temperature. Outputs from the AR6 GCMs are often provided at large spatial scales (on the order of ~100 km) and at daily or longer temporal resolutions. Through downscaling using the MBCn method, the data were refined to approximately 10 km spatial resolution and daily temporal resolution. This report focused on three SSPs (SSP1-2.6, SSP2-4.5, and SSP3-7.0), capturing a wide but plausible range of future emission scenarios. The PCIC data was selected for this project because the temporal and spatial resolution of the data, in particular the availability of daily downscaled data allows for better characterization of the climate extremes, especially for precipitation.

The ClimateData.ca projections used in this analysis were based on a CMIP6 multi-model ensemble of 26 climate models for temperature and precipitation contained in the CanDCS-M6 and CanDCS-U6 datasets. The number of models included for each SSP reflects model availability for that scenario and variable, as not all CMIP6 models provide complete simulations across all SSP pathways (ECCC, n.d.).

As no single model or climate scenario can fully capture the range of uncertainties in future climate conditions, the analysis used a multi-model ensemble approach to reflect the full distribution of projections available from the ClimateData.ca dataset. Percentiles were used to express future projections relative to the ensemble, including the 50th percentile (median) value across all contributing models.

The model projections can be summarized across different time horizons. The time horizons applied to this study include the following:

- 1991 to 2020 (model baseline);
- 2011 – 2040 (used for near-term “2025-2040” calculations);
- 2041 to 2070 (2055s or mid-century);

- 2071 to 2100 (2085s or end-of-century).

Results are also presented for the 2025-2100 period. Note that this long-run period represents a continuous calculation beginning in 2025 and extending through 2100, and is not an average of the near-, mid-, and late-century windows. The results presented in this report reflect the median values (50th percentile) from the SSP2-4.5 multi-model ensemble available from ClimateData.ca. Section 3.5 presents additional results across other emissions scenarios and outlines how projected outcomes differ under lower- and higher-warming pathways.

2.2.2 Selecting Infrastructure-Relevant Climate Indicators

Future climate extremes were projected using extreme indices that are based on both temperature and precipitation variables (**Table 2.1**).

The indicators in **Table 2.1** were selected as they represent the temperature and precipitation conditions that are strongly linked to infrastructure performance in Canadian engineering research and climatic design standards. Indicators such as cooling and heating degree days, maximum temperatures, and the frequency of hot days describe thermal loads that influence pavement softening, rutting, material expansion, and building HVAC demand (Cannon, 2020; Maadani, 2021). Precipitation-based indicators, including annual totals, multi-day accumulations, and short-duration extreme rainfall, capture the moisture and hydraulic stresses that affect drainage systems, road subgrades, infiltration into wastewater networks, and building envelope performance (Sharmin, 2026).

These indicators align with variables used in Canadian building and infrastructure codes, which rely on temperature- and precipitation-based design values to define loading, moisture exposure, and system capacity (Cannon, 2020). As a group, they capture both the chronic trends and short-duration extremes most relevant to deterioration modelling and long-term infrastructure cost analysis in Canada.

Table 2.1: List of climate indices used in the analysis

Indicator Name	Definition	Units
Annual Total Precipitation	Annual total precipitation (PRCP) in wet days where the daily precipitation is greater than or equal to 1 mm	mm
Humidity Index	The number of days with a maximum Humidex (HX) over 30	Days
Max 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	mm
Max Tmax	Monthly maximum value of daily maximum temp	ºC
Cooling Degree Days	The number of degree days accumulated above 18°C	ºC
Heating Degree Days	The number of degree days accumulated below 18°C	ºC
Annual number of hot days (above 27°C)	Annual count of days when mean daily temperature is greater than 27°C	Days
Annual number of hot days (above 30°C)	Annual count of days when mean daily temperature is greater than 30°C	Days

Indicator Name	Definition	Units
Annual number of hot days (above 32°C)	Annual count of days when mean daily temperature is greater than 32°C	Days
Annual number of hot days (above 35°C)	Annual count of days when mean daily temperature is greater than 35°C	Days
Mean July daily maximum temperature (°C)	July mean value of daily mean temperature	°C

The projected magnitude in extreme precipitation depths for short durations (15-min, 2-hour, and 24-hour) and various return periods (2-, 10-, 15-, 25-, 50-, and 100-year) were derived from ClimateData.ca. These projections were generated using a temperature scaling approach which relied on the assumption that increased temperatures drive atmospheric moisture holding capacity, through the Clausius–Clapeyron relationship, resulting in the potential for greater extreme rainfall amounts.

2.2.3 Defining Climate Representative Regions for National Modelling

For national-scale modelling, the analysis grouped infrastructure locations into climate-representative regions and applied climate projection data at the regional level. This approach allowed all assets within a region to be assigned climate conditions that reflect the dominant temperature and precipitation patterns for that area. Climate projections for temperature and precipitation were generated for each climate-representative region and applied consistently across all assets within that region, ensuring coherent and comparable climate adjustments across the model.

The rationale for this approach was twofold. First, the distribution of infrastructure across Canada is extensive and highly varied. Applying climate projection data at the level of every individual municipality would introduce substantial computational complexity and reduce analytical feasibility. Second, grouping municipalities into regions with similar climate regimes allowed the analysis to capture meaningful differences in climate exposure across the country while maintaining a nationally consistent methodology.

The Köppen Geiger climate classification system provided a practical and transparent basis for creating these regions. It organizes land areas according to long term patterns in temperature and rainfall, making it suitable for clustering municipalities that experience comparable climate regimes. The classification has been widely used in climate and ecological studies and was recently updated at one kilometer resolution, providing a detailed and well documented set of climate classes for both historical and future periods (Beck, 2023). This makes Köppen Geiger an appropriate and scientifically supported framework for defining climate representative regions in a national infrastructure model.

In this analysis, the Köppen Geiger classification was used to identify climate representative locations, with population information incorporated to prioritize municipalities with greater infrastructure exposure. This process involved three steps:

- For each municipality, the percentage coverage of Köppen Geiger classes during the 1991 to 2020 period was calculated using the area of the municipal boundary (Beck, 2023);
- A clustering algorithm was then applied to group 1011 municipalities into 20 clusters based on their Köppen Geiger class composition. Each cluster was constrained to include only municipalities that fall within the same ecozone, as defined by the Terrestrial Ecozones Map from the Atlas of Canada (Government of Canada, Agriculture and Agri-Food Canada, Science and Technology Branch, 2013); and
- From each cluster, the municipality with the highest population was selected as the representative location.

These climate representative regions provided the foundation for applying climate stressors in the deterioration model. Climate projections for temperature and precipitation were generated for each region and applied consistently across all assets within that region. This approach maintained analytical feasibility while ensuring that climate driven cost adjustments reflected meaningful regional differences.

Figure 2.2 illustrates the distribution of climate-representative regions across Canada.

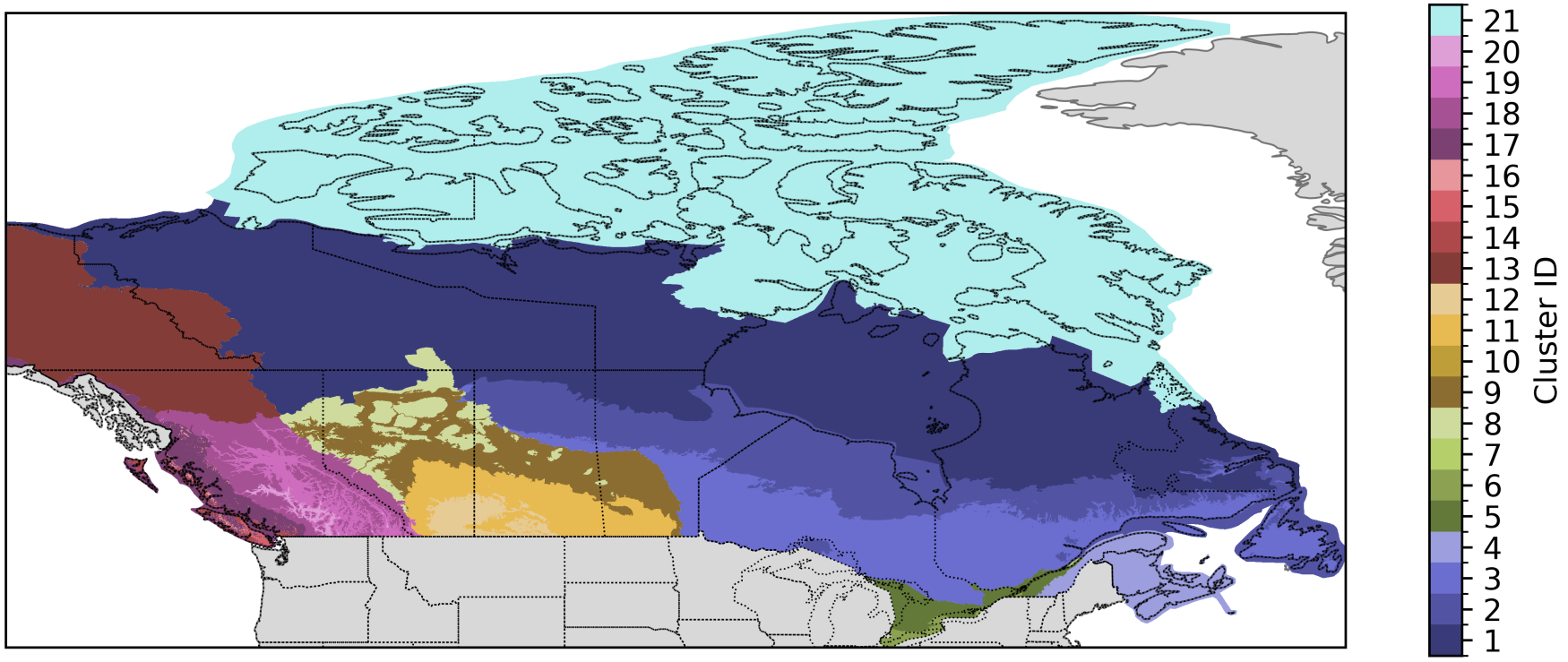

Figure 2.2: Climate representative regions

2.3 Asset Deterioration Modelling

The asset deterioration model used in this analysis provided the structured way to translate the physical characteristics of infrastructure assets into long-term estimates for maintenance, rehabilitation, and replacement needs. To support the analysis, attributes including construction year, current condition state, replacement value, useful service life (USL), were used to develop deterioration curves and to place the asset on the correct part of the curve, supporting asset level lifecycle assessments. These curves were adjusted for climate specific scenarios; to reflect the impact these effects have on each asset class/type. Without this model, it would not be possible to estimate when interventions will be required, how often they will occur, or how these needs accumulate across the national inventory.

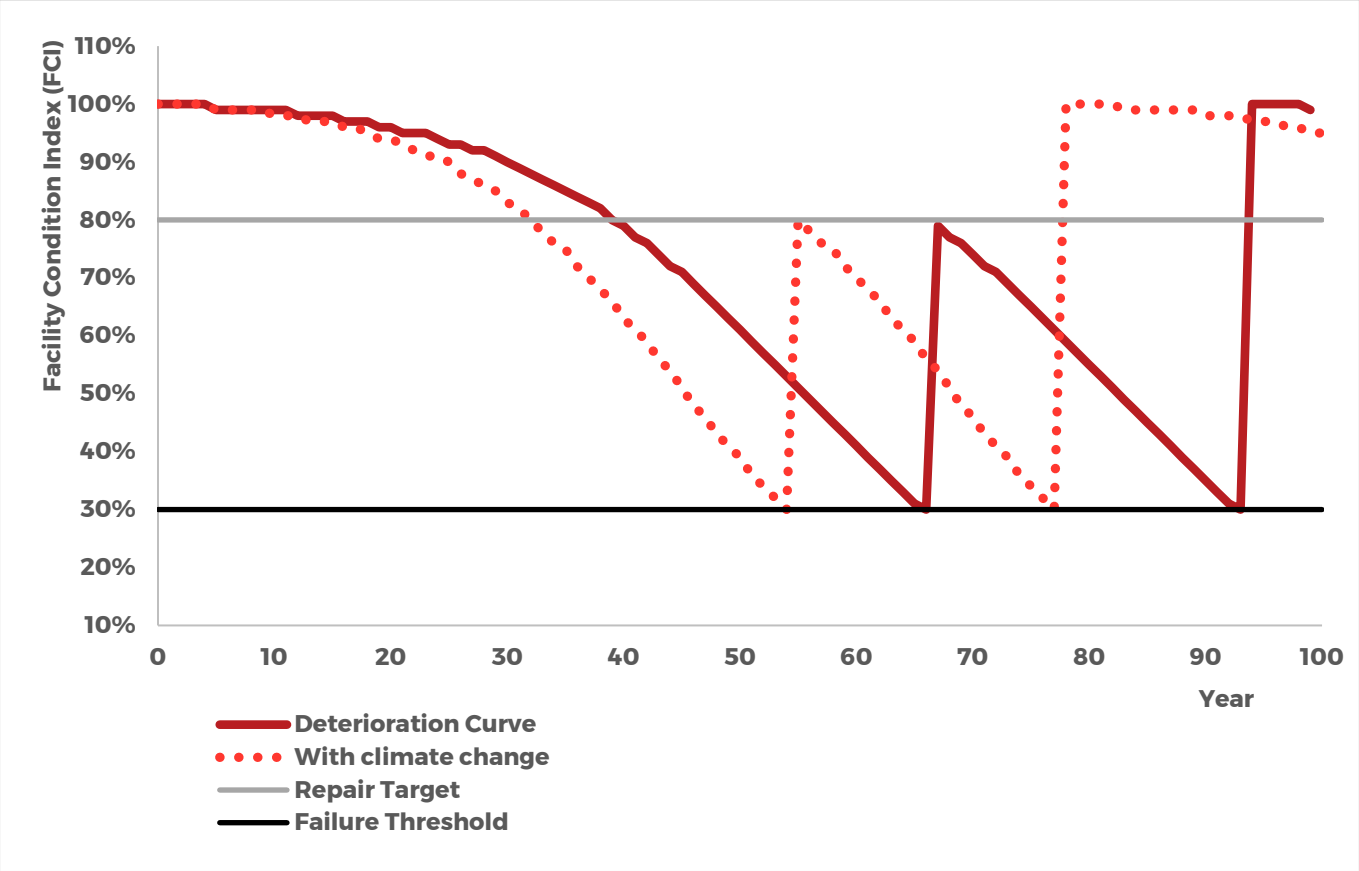

Figure 2.3: Example deterioration curves under stable and climate adjusted conditions

Figure 2.3 shows how an asset naturally deteriorates over time (solid red line) and how climate change accelerates that deterioration (dotted red line). The downward slopes represent the asset's aging and losing condition, while the sharp upward jumps show major repairs or replacements that restore it to a state of good repair. Under climate change, the asset follows the same cycle, but each deterioration slope is steeper, due to the shortening of the estimated service life - meaning it reaches repair and failure thresholds sooner. Even after the asset is renewed, it deteriorates faster in a more climate-stressed

environment, with shorter useful lives resulting in more frequent interventions. As represented in this analysis, rehabilitation events return the asset only to a partial state of repair rather than resetting its condition entirely, which shortens the interval to the next replacement window. In addition, the timing of interventions is shown as fixed points for clarity; however, more complex asset-level engineering models typically allow intervention timing to vary within a window, reflecting the broader range of performance outcomes observed in practice.

The model began with the combined national asset inventory, using representative values for construction year, condition state, useful service life, and replacement value. With this information, it projected how each asset grouping progressed through its expected life cycle under typical operating conditions. As condition deteriorates over time, a set of decision rules determined the type and timing of interventions:

- Assets in good condition received routine maintenance;
- Assets that approached mid-life or showed material deterioration were programmed for rehabilitation; and
- Assets that reached the end of their useful service life were renewed.

The computational lifecycle model generated a profile that showed when each asset grouping required maintenance, repair, or replacement over many decades, producing the benchmark forecast of long-term infrastructure needs. This baseline formed the foundation for evaluating how climate conditions accelerated deterioration, shifted intervention timing, and increased future investment requirements.

To support national scale modelling, the analysis grouped assets rather than modelling each one individually. Groupings reflected combinations of asset type, climate representative region, construction period, and provincial or territorial ownership. For instance, all small culverts in Alberta, in climate regions #2, built between 2020 and 2022, owned by municipalities and local governments, were considered similar (i.e., they have same useful service life, similar condition, and were replaced in the same year, experienced the same climate impacts, etc.). Each grouping was assigned representative characteristics drawn from Statistics Canada and certain elements adapted from the FAO of Ontario model. This approach maintained consistency and computational efficiency while capturing meaningful variation across infrastructure types and geographic conditions. This grouping strategy was considered appropriate for a national-scale assessment, where the objective is to compare cross-regional effects rather than to model the performance of individual assets. If the aim were to represent localized conditions or site-specific variability, a single-asset modelling approach would have been required.

The model used these groupings to generate annual projections for all scenarios (see **Section 2.5**). These projections included:

- Useful service life;
- Repair timing and expected repair frequency;
- Annual operations and maintenance needs;
- Annual replacements.

- Cumulative repairs and replacements;
- Cumulative climate resilient interventions (depending on the adaptation pathway); and
- Thirty-year moving averages for maintenance and replacement rates.

Using thirty-year moving averages helped smooth out short term fluctuations caused by demographic turnover in infrastructure and highlighted long term trends in lifecycle needs.

As many inputs included ranges rather than precise values, the model used representative values to maintain tractability. For example, if a group of assets were built over a twenty-year period, the model assigned a median construction year; if useful service life spanned a broad range, a midpoint value was used. This simplification process ensured that the analysis remained computationally manageable while still reflecting expected lifecycle behaviour at a national scale. In effect, the approach relies on the law of large numbers: when aggregated across hundreds of thousands of asset groupings, these representative values tend to balance out, producing stable cross-regional patterns even though individual assets may differ from their group-level averages.

The model also incorporated replacement and retrofit costs to represent the cost of upgrading assets at the time of intervention. Replacement costs were applied when an asset was renewed and were structured as step changes aligned with the three thirty-year periods of the analysis, reflecting how standards evolve over time. Retrofit costs applied when assets fell below the state of good repair threshold and required significant repair. For assets with relatively short service lives, the model applied only the climate conditions relevant to the period within which those assets operated, recognizing that designing for distant future conditions was neither efficient nor appropriate, as these assets would be replaced multiple times before far-future climate states occur and therefore would not experience those future conditions during their operational life.

Together, each aspect of deterioration model created a consistent and transparent framework for estimating the timing and magnitude of lifecycle interventions across Canada's public infrastructure. The deterioration model defined how assets age and when they required investment under stable climate conditions. Climate adjustments were then layered onto this baseline to quantify how changes in temperature and rainfall alter deterioration patterns and influence long term infrastructure costs.

2.4 Climate Impact Modeling - Temperature & Precipitation

Climate change modifies the rate at which public infrastructure deteriorates, by altering the environmental conditions that assets experience over their service lives. The purpose of this step in the modelling framework was to apply projected changes in temperature and precipitation to the baseline deterioration pathways outlined in **Section 2.3**. These climate adjustments allowed the analysis to quantify how rising heat and increased rainfall accelerate infrastructure wear, shift intervention timing, and increase long term lifecycle costs.

Temperature and precipitation were the focus of the analysis because they represent the most widespread and consistently measurable climate hazards affecting the asset types included in this study. As outlined in the CCI's *Prepare or Repair* report, increased temperature and increased rainfall have clear and well documented effects on roads, public buildings, stormwater systems, and wastewater systems (Ness, Carriere, & Gauer, 2026). Pavements soften and deform under prolonged heat, building systems face greater thermal expansion stresses, and stormwater and wastewater systems experience higher hydraulic loads and moisture-related deterioration. These hazards also had reliable national scale datasets and established relationships with asset performance, which made them suitable for integration into a national deterioration modelling framework.

The climate impact modelling step applied projected changes in temperature and precipitation to alter the deterioration trajectories generated in the baseline model. These climate driven adjustments influenced the lifecycles of asset groupings in several ways:

- Maintenance cycles become more frequent as assets are exposed to more intense heat or moisture over time.
- Rehabilitation is needed sooner when climate conditions erode performance earlier than expected when compared to assets in a stable climate.
- Replacement events occur earlier or more often, increasing long term capital needs relative to the baseline.
- Useful service lives are shortened when chronic heat and moisture exposure accelerate material fatigue, corrosion, or structural decline.

In this way, climate information acted as a deterioration modifier, shifting the timing and magnitude of interventions rather than altering the underlying logic of the computational model.

Role of Alpha Coefficients in Climate Impact Modelling

A central component of the climate impact modelling was the use of alpha coefficients, which quantified the sensitivity of infrastructure costs to changes in climate variables. Alpha coefficients were initially developed in 2021, specifically for the FAO of Ontario to support the integration of climate risk considerations into cost assessments. In this study, the Ontario coefficients are adjusted to reflect the expected trend in climate representative regions.

Alpha coefficients ($\alpha_{i,c}$) captured how a percentage change in temperature or precipitation can lead to a corresponding percentage change in costs. This coefficient is defined as the ratio between the change in a specific cost (Δp) and the corresponding climate variation (Δc), expressed as:

$$\alpha_{i,z} = \frac{\Delta p_z}{\Delta c_z}$$

where:

i refers to the type of cost (e.g., USL, O+M, retrofit, or replacement),

z represented the component being analyzed.

These coefficients allowed the model to translate projected climate changes into adjustments that modified the pace of deterioration and shifted lifecycle costs relative to the baseline. For example:

- If temperature increased by 1% and the alpha coefficient for useful service life is negative, the model used a shortened the lifespan.
- If rainfall intensity rose, the model increased operations and maintenance costs or accelerated rehabilitation timing depending on the alpha value for that category.

By applying these adjustments across all asset groupings and climate representative regions, the model produced climate adjusted trajectories that reflected the additional lifecycle costs associated with future climate conditions.

The climate impact modelling step enabled the comparison of adaptation strategies by showing how earlier or delayed upgrades alter outcomes under different climate conditions. Since climate change shifted intervention timing and increased cost pressures, adaptation decisions (such as whether upgrades occur proactively or only at the point of replacement) produced different lifecycle cost profiles. The climate adjusted results therefore provided the basis for comparing the no adaptation, reactive adaptation, and proactive adaptation scenarios.

2.5 Defining Adaptation Scenarios and Modelling Logic

To assess the potential impacts of climate change on public infrastructure, the analysis applied four scenarios: a baseline scenario and three climate change scenarios that differ in how and when adaptation measures were applied.

At the core of each scenario was a set of decision rules that determined when an asset was upgraded to climate resilient standards and how climate driven deterioration affected it's lifecycle. These rules were consistently applied to all assets within a scenario, to understand the impact that differing climate effects have on asset management costs.

Each scenario adjusted the internal model logic in the following ways:

- **Timing of adaptation:** when, if ever, an asset is upgraded to climate resilient standards
- **Exposure to climate stressors:** whether the asset continues to deteriorate under climate adjusted conditions or receives an adaptation upgrade that resets part of its deterioration pathway
- **Lifecycle cost outcomes:** how earlier or delayed adaptation shifts operations and maintenance costs, rehabilitation needs, and replacement timing

The modelling results as they relates to each scenario are summarized in **Table 2.2**.

Table 2.2: Scenario definitions and modelling decision rules[1]

Scenario	Definition	Model Assumptions
Baseline	Represents asset deterioration and lifecycle costs under a stable climate with no climate change	▪ Assets follow their normal useful service life with no climate adjustments applied. ▪ Maintenance, rehabilitation, and replacement occur based solely on age and condition. ▪ No adaptation upgrades are applied. ▪ Serves as the reference case for comparison with climate adjusted scenarios.
No Adaptation	Climate change is incorporated, but assets are never upgraded to climate resilient standards. Assets remain fully exposed to climate driven deterioration.	▪ Climate adjusted deterioration rates shorten service life and increase O&M needs. ▪ At replacement, assets are replaced to their original (non-resilient) standard. ▪ Assets continue to experience full climate impacts in all subsequent cycles. ▪ All assets follow the same rule: no asset is adapted at any time.
Reactive Adaptation	Assets are adapted only at the point of replacement, resulting in gradual system wide resilience over time.	▪ Assets experience climate driven deterioration until they reach end of life. ▪ At replacement, assets are replaced with climate resilient versions, resetting deterioration to a less climate sensitive pathway. ▪ No early adaptation occurs at mid-life rehabilitation. ▪ Adaptation spreads gradually as assets reach renewal age.
Proactive Adaptation	Assets are adapted at the earliest opportunity, either during major rehabilitation or at full replacement, accelerating the transition to a resilient system.	▪ If an asset reaches a major rehabilitation point, it is replaced (not repaired) with a climate resilient version. ▪ If an asset does not require major rehabilitation, it is adapted at full replacement. ▪ Earlier adaptation reduces sensitivity to climate stressors and delays future deterioration. ▪ All assets follow the same rule: adapt at the first qualifying intervention event.

The results of the modelling are presented in Section 3 to enable clear comparison of long-term infrastructure costs, climate-related impacts, and the benefits associated with different adaptation timings.

2.6 Aggregation and Reporting

Assets were grouped into broader categories that balance modelling feasibility with the need for geographic and asset specific detail. To create these categories, several attributes were used, including:

[1] The scenarios are analytical constructs, not predictions of government behavior. All assets within a given scenario follow the same decision rules, supporting comparability across scenarios. Differences in results arise from the timing of adaptation and the extent to which assets remain exposed to climate adjusted deterioration. Scenario outcomes should be interpreted as demonstrating the relative impact of earlier or later adaptation on lifecycle costs and infrastructure resilience.

- Asset type, covering approximately one hundred and fifty categories
- Climate representative region, across twenty-one climate clusters
- Construction period, based on seven construction eras from the Core Public Infrastructure Survey
- Province or territory, with federal assets grouped separately

The categorization led to more than three hundred thousand distinct asset groupings (a reduction from the total 4.5 million individual assets), which struck a balance between detailed results and efficient memory use during calculations. For each grouping, the model assigned representative values for key parameters, including useful service life, construction year, operations and maintenance needs, and expected repair and renewal patterns, using Statistics Canada data and selected elements adapted from the FAO of Ontario methodology.

Once deterioration and climate adjustments were simulated for each grouping, the model aggregated costs to produce meaningful outputs at provincial, territorial, and national scales. The aggregation process was designed to reflect differences in infrastructure portfolios, climate exposure, and replacement values across jurisdictions, while maintaining consistency in how results are interpreted.

A key aspect of the aggregation process was the use of intervention cost measures, expressed as a percentage of the CRV of assets rather than as direct dollar amounts at the asset level. This approach was necessary because the CPIS does not fully align its physical asset inventory (for example, number of assets or kilometres of network) with its replacement value estimates. As a result, asset level dollar values cannot be consistently derived from the survey. This method preserved the comparability and internal consistency of results, while recognizing the structural limitations of the underlying national dataset.

To produce the intervention cost summaries, the analysis applied an approximation method:

- Costs were first calculated as a percentage of CRV for each asset grouping (for example, climate related deterioration may increase costs by 1% of CRV each year).
- These percentages were then applied to aggregate CRV totals for each province, territory, and asset class to generate dollar estimates.

For example, if road assets in Alberta had a CRV of $800M and the model estimated a climate impact equal to 1% of CRV in 2050, the corresponding cost was $8M for that year.

The CPIS also supported aggregation by providing replacement value and condition estimates at consistent geographic and asset type scales. As CRV values inherently reflect regional construction cost differences, using CRV-based weighting allowed the aggregation to account for regional cost variability without requiring additional regional cost adjustment factors. These values formed the basis for weighting deterioration and climate adjustments across regions.

The outputs produced through this aggregation process include:

- Annual and cumulative maintenance, repair, and replacement needs

- Climate related deterioration impacts by asset type and region
- Comparisons across adaptation scenarios
- Provincial, territorial, and national cost estimates expressed in both percentage and dollar terms

Together, these steps allowed the analysis to translate detailed modelling outputs into clear, comparable, and policy relevant findings. The aggregated results for each scenario are presented in Section 3.

2.7 Calculating Benefit-Cost Ratios

This section outlines the methodology that was used to calculate benefit–cost ratios (BCRs). BCRs were derived only after all lifecycle costs were modelled, climate-adjustment factors were applied, and intervention cost results were aggregated across provincial, territorial, and national scales. The purpose of this step was to evaluate whether proactive adaptation yielded net benefits when compared to the long-term costs associated with reactive, business-as-usual asset management under a changing climate. By quantifying how climate change accelerated deterioration, and how resilient design mitigates those effects, the BCR analysis offered a consistent economic basis for comparing different adaptation scenarios.

In BCR analysis, benefits represented the avoided future costs attributable to climate stress. These included avoided increases in operations and maintenance (O&M), repairs, and early replacements relative to a baseline scenario without adaptation. Costs represented the additional expenditure required to upgrade or retrofit an asset to a resilient standard.

Benefits and costs were both expressed in present-value terms using the discounting assumptions selected for the analysis (e.g., real discount rate, price escalation, timing of expenditures). Climate-related cost adjustments, derived from exposure–vulnerability modelling and asset deterioration curves, were applied consistently across all assets and all climate scenarios.

For each year in which an asset is built or replaced with a resilient design, the BCR compared the *adaptation cost* paid in that year with the *stream of future climate-related costs avoided* over the asset's remaining service life.

The calculation was given by:

$$BCR(t) = \frac{\sum_{(i=t)}^{(t+L)} [\, \Delta O\&M_i + \Delta Repairs_i + \Delta Replacements_i \,]}{AdaptationCost(t)}$$

Where:

- t: year when the asset is replaced or adapted
- L: remaining useful service life of the asset
- $\Delta O\&M_i$: additional O&M costs in year $i$due to climate change
- $\Delta Repairs_i$: increased repair costs in year i

- $\Delta Replacement_i$: increased replacement-related costs due to climate stress
- Adaptation Cost: the resilience cost for retrofit or resilient replacement

This formulation allowed each BCR to reflect the actual timing of deterioration, adaptation investments, and climate stress, rather than simply comparing static or hypothetical cost streams.

The final BCR metrics presented in the report reflect a weighted average of annual asset-level results across all asset subtypes, all climate scenarios included in the model, provincial, territorial, and national scales, and the relative replacement volumes and timing of each asset class

This weighting allowed higher-value, higher-exposure assets to appropriately influence the national result, while preserving the diversity of outcomes across regions and infrastructure categories.

Why BCRs Can Decrease Over Time

A common misconception is that increasing climate impacts necessarily increase the BCR of adaptation. However, in long-term modelling, BCRs may decrease as climate stress intensifies. This occurs when:

- the adaptation cost grows at a faster rate than the future climate-related costs that are avoided; or
- climate-adjusted replacement costs rise linearly, while the rate of increase in avoided deterioration costs slows or plateaus; or
- resilient design requirements become significantly more expensive as climate thresholds (e.g., stormwater capacity, design flood levels, thermal tolerance limits) escalate.

In such cases, although the absolute value of avoided climate damages increases, the relative advantage of paying for resilience can be eroded if the cost of achieving resilience grows more quickly than the damages avoided. This is especially relevant under high-emissions scenarios, where design thresholds escalate sharply and where retrofitting requirements become more complex and costly over time.

Note that, for some asset types, climate change can also have net positive effect (e.g., reduced freeze-thaw deterioration or lower heating demand). In these cases, the amount of damage that adaptation would otherwise avoid declines, reducing the benefits component of the BCR and resulting in lower ratios. Although the hazards included in this study all increase deterioration, this dynamic is

2.8 Estimating Flooding Damage and Adaptation Costs

Flooding required a separate analytical treatment because the assessment drew on dedicated external datasets - specifically, flood hazard projections from CCI and historical loss records from Catastrophe Indices and Quantification Inc. (CATIQ). These datasets describe flood exposure and event-level losses using different spatial structures, return periods, and risk metrics than those used in the deterioration-based framework for temperature- and rainfall-driven impacts. In addition to the different data requirements, flooding represents an acute, event-driven hazard rather than the chronic deterioration

processes modelled in the heat- and precipitation-modelled approach, and therefore could not be integrated into the lifecycle model in a consistent or meaningful way. As a result, As a result, a separate high-level flood analysis was conducted to complement the deterioration modelling and capture the economic implications of flood-protection investments.

The purpose of this flood analysis was not to quantify direct damage to public infrastructure, but rather to assess the scale and economic value of investing in structural flood protection. Flooding is a growing national hazard that necessitates dedicated protective works, such as dikes, seawalls, floodwalls, and building elevation, to reduce risk across communities. The analysis evaluated where these measures were likely to yield net benefits and estimates the potential magnitude of avoided future flood losses they could deliver at a national scale.

2.8.1 Estimating Historical Flood Losses

This component of the analysis established a high-level benchmark for how past flooding has affected communities across Canada. As no national dataset existed that directly recorded infrastructure-specific flood damages, insured losses to residential and commercial buildings were used as a proxy for the broader consequences that occur when infrastructure systems are exceeded during extreme events. These insured losses provided a nationally consistent indication of the frequency, severity, and geographic distribution of flood events linked to infrastructure performance under stress.

Two types of flood-related hazards were reflected in the historical loss data:

- **Sewer backup:** These events often occur when wastewater or stormwater systems exceed their design capacity - for example, when combined sewers surcharge during intense rainfall or when pumping capacity is lost during power outages. In this analysis, sewer-backup losses were treated as an indirect indicator of wastewater and drainage system constraints. To interpret climate-driven variation in future losses (see Section 2.8.2), the analysis assumed that changes in sewer-backup claims reflect changes in system exceedance associated with climate change, recognizing that not all individual backup events can be attributed solely to infrastructure failure.
- **Overland flooding (riverine, coastal, and pluvial):** These losses arise from hydrological processes influenced by rainfall intensity, watershed response, topography, land cover, and drainage capacity. Instead, these losses were treated as broader community impacts that may be mitigated through new structural flood-protection works, rather than through upgrades to individual existing assets.
- To construct this historical record, water-related insured losses were compiled for 2015–2024 using the Historical Catastrophe Database and the Industry Exposure Database maintained by CatIQ. This Canadian platform provides detailed, standardized data on natural and human-made catastrophes for insurers, reinsurers, and public-sector stakeholders.
- **Industry Exposure Database (IED) -** IED is a dataset of Canadian property insurance exposure, derived from aggregated submissions by most insurers in 2024. It provides a representation of national exposure, reporting sums insured at the Forward Sortation Area (FSA) level and classified by line of business (residential, commercial, industrial, auto) as well as by coverage type (Residential,

Commercial, Auto) as well as by coverage type (flood, or sewer back-up) (Catastrophe Indices & Quantification Inc. [CatIQ], 2024).

- **Historical Catastrophe Database -** This database covers Canadian catastrophe events (floods, wildfires, ice storms) from 2015–2024, providing monthly insured-loss estimates, associated meteorological and hazard data, and locations reported at regional designations (e.g., Southern British Columbia, Greater Toronto Area, St. Lawrence Valley) or at the municipal level (Catastrophe Indices & Quantification Inc. [CatIQ], 2024).

Flood event records originate from multiple sources and are reported using inconsistent geographic descriptors, ranging from individual municipalities to broad regional labels. To enable consistent analysis, these data were first harmonized to a common spatial framework. Losses were aggregated at the forward sortation area (FSA) level (the first three characters of a Canadian postal code, representing a standardized geographic unit), which provided a nationally consistent geography and aligns with the resolution of available exposure data, enabling comparability across regions and events.

When flood events were reported for large regions or spanned multiple jurisdictions, total losses were allocated across affected areas, using an exposure-weighted approach. Losses were first distributed across provinces in proportion to their insured exposure and then further allocated to FSAs based on their relative exposure by line of business (i.e., the insurance categories used by CatIQ such as residential, commercial, industrial, and auto) and flood peril. This approach allowed for event losses to be spatially distributed in a manner that reflects the underlying distribution of insured assets rather than administrative boundaries or reporting conventions.

The result was a nationally coherent approximation of historical flood losses that captured the magnitude and location of events. This dataset provided the empirical foundation for estimating potential future losses and served as the reference point for evaluating the benefits of structural flood-protection measures addressed in later steps of the analysis.

2.8.2 Estimating Future Flood Losses

The forward-looking flood analysis estimated how future climate conditions influence flood related losses and assessed the extent to which structural protection measures reduced those losses. As in the historical assessment, all loss estimates were modelled at the building level rather than the infrastructure asset level. This building-level focus provided a consistent national basis for analysis and reflects the fact that flood damage to buildings often occurs when adjacent public systems, such as stormwater, wastewater, or overland drainage infrastructure, exceed their design capacity.

FSA level projections were developed of future flood losses by aggregating building level outputs from the Canadian Climate Institute's *Close to Home* project (50th percentile damage estimates) (Ness, Miller, Florez Bossio, Pelai, & Carriere, 2025). These projections describe expected annual losses for residential and commercial buildings under current and future climate conditions, covering riverine, coastal, and pluvial flooding. As these projections are generated independently from observed insurance claims, they were not calibrated directly to historical loss data.

To integrate projected changes with the historical loss record, the analysis applied the relative change between current and future damages from *Close to Home* to the CatIQ historical loss dataset at the FSA level. This scaling used locally or regionally derived ratios of future-to-current damage, producing adjusted loss estimates that reflect both historical experience and projected shifts in hazard intensity. These adjusted losses were interpreted as indicators of community level exposure to flooding and used to identify locations where protective infrastructure may be economically justified.

All projected buildings were spatially assigned to FSAs Where a building point fell outside an FSA polygon, it was linked to the nearest FSA using a k nearest neighbour approach (k = 1). For each FSA, total projected losses were then allocated across perils and building categories using the historical distribution of losses. Provincial level exposure shares from CatIQ, disaggregated by peril (overland flood, sewer backup) and by insurance line of business, were used as weighting factors to maintain consistency with observed historical patterns and to distinguish loss components relevant to different types of adaptation measures.

Losses were summarized for two storylines:

- Unprotected scenario: no additional structural flood protection in place; and
- Protected scenario: feasible structural protection measures implemented.

The difference between these two conditions represents the estimated avoided losses attributable to protective works.

2.8.3 Projected Adaptation Costs to Flooding-Related Losses

The forward-looking flood analysis also included an assessment of the costs and benefits of structural flood-protection measures, such as dikes, seawalls, floodwalls, and elevation of structures. The purpose of this analysis was to identify where protective infrastructure is likely to provide positive economic returns by reducing future flood losses. This assessment of structural protection options aligned with the broader objective of evaluating how new protective works can complement upgrades to existing public infrastructure and help manage the growing risks associated with riverine, coastal, and pluvial flooding.

To evaluate this protective infrastructure, the analysis drew on a well-established body of coastal and inland flood-protection modelling frameworks, including the economic screening approaches developed by (Neumann, Chinowsky, Helman, Black, & Ludwig, 2020), (Yohe, Neumann, & Marshall, 1995), and (Nicholls & Tol, 2006), and subsequent applications in large-scale flood-risk studies. Structural protection was tested using a benefit–cost approach that compares the full life-cycle cost of a measure, including capital expenditures and ongoing operations and maintenance, with the present value of the flood losses that the measure is expected to avoid. A discount rate of 0% was assumed and the time-horizon considered ended by end of century. Protection was adopted where avoided losses exceed costs – that is, where the BCR is greater than 1. Where this condition was not met, the area was treated as unprotected and corresponding losses are retained. This approach reflected common practice in national flood-risk

assessments and provides a consistent basis for screening protection options across diverse geographic contexts (e.g., in CCI's *Under-Water Report*) (Ness et al., 2021). [2]

Avoided losses were calculated by comparing flood extents and building-level damages under protected and unprotected conditions. Protective measures were assumed to reduce inundation driven by elevated river, lake, or coastal water levels, rather than rainfall-driven ponding or sewer surcharge, allowing the analysis to isolate the portion of flood risk that shoreline or riverbank protection can realistically address. The difference in damage between these two states represented the flood losses that structural protection can be averted over time.

In locations where shoreline protection was not cost-effective, the analysis evaluated increasing the building elevation as an alternative measure. Elevating a building reduces the depth of flooding it experiences, resulting in lower damage costs. As with other measures, elevation was assumed only where the reduction in expected flood losses outweighed the cost of the intervention (i.e., BCR is greater than or equal to 1).

This structured evaluation of adaptation options provided a high-level understanding of where protective infrastructure could play a meaningful role in reducing Canada's future flood losses. While the analysis does not prescribe site-specific project designs, it offers a transparent and nationally consistent indication of which regions may warrant investment in structural protection. Combined with the deterioration-based modelling of temperature- and rainfall-driven impacts, this component allowed both chronic and acute climate risks to be reflected in the overall assessment of Canada's long-term infrastructure needs.

A more detailed description of the methods used to estimate adaptation costs for flooding-related losses is presented in **Appendix B**.

2.9 Key Limitations and Assumptions

The results of this study were shaped by several important limitations. These limitations arose from gaps in underlying datasets, the need for simplifying assumptions, and the inherent complexity of modelling climate impacts on diverse infrastructure systems across Canada. These limitations include:

- **National asset inventory** - The CPIS provided the most comprehensive national dataset available but does not capture all public infrastructure types, is not georeferenced, and contains missing or inconsistent condition reporting for several asset categories. To accommodate these gaps, the analysis used representative values such as median construction years, typical service lives, and generalized condition assumptions, and excluded asset types that cannot be reliably characterized. These adjustments reduced granularity and likely led to conservative results, as assets in poorer conditions or with shorter life spans may be underrepresented.

[2] Adaptations for sewer-backup are excluded as both the hazard and the efficacy of lot-level interventions (e.g., backwater valves) depend on private-side plumbing configuration, installation quality and maintenance, lateral condition, and local network design/operations—inputs that vary widely and are not consistently available at a national scale. Consequently, the sewer-backup share of AAL is removed prior to the adaptation appraisal, ensuring shoreline armoring is not credited with reductions outside its mechanism of action.

- **Climate hazard coverage** - The deterioration modelling focused only on temperature and precipitation-related hazards. Other climate hazards, such as wildfire, permafrost thaw, drought, or coastal erosion, were not considered. However, their omission means that the analysis does not represent the full range of climate impacts that infrastructure may experience. As a result, the asset deterioration modelling presents a conservative estimate of long-term climate-related costs, as the total burden on infrastructure is likely higher when these additional hazards are considered.
- **Flood modelling** - Flooding is represented using national insurance loss and exposure data drawn from CatIQ's Historical Catastrophe Database and Industry Exposure Database. This approach was necessary because national-scale flood modelling requires detailed information on topography, land use, drainage systems, and hydrology that is not available consistently across Canada. While this method supports national comparability, it cannot reflect local flood behaviour or asset-specific damage patterns and therefore produces high-level flood-related costs that may differ from local realities.
- **Climate projection uncertainty** - Climate projections vary across global climate models and emissions pathways, especially for extreme rainfall. While the analysis used ensemble percentiles to reflect a range of plausible futures, it cannot capture the full spectrum of potential climate variability or future extremes. For temperature-related hazards, uncertainty generally resulted in conservative estimates, while for precipitation-related hazards, the direction of uncertainty is more variable and may lead to either underestimation or overestimation of impacts depending on local conditions.
- **Deterioration and cost parameters** - Assumptions were required for service lives, deterioration rates, repair thresholds, and O&M sensitivities. In this analysis, deterioration was realized through changes in annual O&M requirements, the timing of repairs and major rehabilitation, and the shortening of useful service life, which together determined when assets required intervention and how climate stress alters those timelines. Where empirical data were limited, the study relied on generalized parameter values adapted from Statistics Canada datasets and selected elements of the FAO of Ontario methodology. These simplifications support consistency across asset classes and regions but may not fully capture localized or asset-specific performance patterns. As a result, deterioration may be under- or over-represented for assets exposed to highly localized climate conditions or atypical usage patterns, contributing to uncertainty that varies among asset types.
- **Aggregation-related sensitivities -** The reporting structure relied on disaggregating results by asset type and province and then averaging outcomes over multi-decade periods. This approach was necessary for computational efficiency but it introduced sensitivities related to the timing of interventions, the interaction between adaptation and baseline renewal cycles, and the translation of detailed life-cycle simulations into aggregated provincial and national summaries. These sensitivities can produce small discrepancies between disaggregated and fully aggregated results, including occasional near-zero residual values once grouped at the provincial or asset-type level. These reflect model aggregation behaviour rather than changes in underlying climate impacts.
- **Modelling system interactions** - The modelling framework treated each asset class independently and did not simulate interdependencies between infrastructure systems. In practice, failures in one

system, such as stormwater or wastewater, can accelerate deterioration in others, such as roads or public buildings. As these interactions are not captured, the analysis does not account for cascading impacts that occur during extreme events. The absence of system-level dynamics generally results in conservative cost estimates, as real-world impacts tend to compound across interconnected networks.

- **Representation of economic impacts** - The analysis quantified only direct infrastructure costs related to maintenance, repair, rehabilitation, replacement, and adaptation. It did not account for broader economic consequences such as business interruption, supply chain delays, productivity losses, or social and health impacts. These broader impacts can be substantial during infrastructure failures. Their exclusion narrows the assessment and results in conservative estimates relative to the full economic impacts of climate change.
- **Fiscal and behavioural realism** - The model assumed that interventions occurred when physically required and did not incorporate real-world budget constraints, administrative barriers, or behavioural responses that often delay infrastructure upgrades. In practice, deferred maintenance or delayed adaptation can significantly increase long-term costs. By assuming optimal timing, the analysis produces cost trajectories that are generally conservative when compared with those that may occur under real-world fiscal limitations.

3. Results

This section presents the key findings from WSP's analysis of climate change impacts on Canadian public infrastructure. The results begin with baseline projections and expand to include the additional costs and damages associated with infrastructure failure under changing climate conditions, followed by the costs and benefits of proactively and reactively adapting to these changing conditions. **Table 3.1** below provides an overview of the main results and the corresponding report sections, helping readers navigate the breadth of findings and locate specific topics of interest.

Table 3.1: Summary of results section

Result Section & Title	Description
Section 3.1 - Canada's Aging Infrastructure Portfolio	This section presents baseline projections of long-term infrastructure costs under a stable climate, including maintenance, rehabilitation, and replacement requirements associated with normal aging. It summarizes the condition and age distribution of Canada's infrastructure portfolio and quantifies the annual costs required to maintain a state of good repair without climate change influences.
Section 3.2 – Canada's Infrastructure in a Changing Climate	This section provides climate-adjusted cost projections showing how rising temperatures and increased precipitation accelerate deterioration. It quantifies additional operations, maintenance, repair, and replacement costs attributable to climate change above the baseline, and highlights differences by asset type, region, and order of government.
Section 3.3 – Adapting Canada's Public Infrastructure	This section compares the lifecycle cost outcomes of no adaptation, reactive adaptation, and proactive adaptation scenarios. It shows how adaptation timing affects deterioration pathways, intervention frequency, and long-term cost trajectories across all asset classes and jurisdictions.
Section 3.4 – Costs and Benefits of Adaptation	This section evaluates the cost-effectiveness of proactive and reactive adaptation using benefit-cost ratios (BCRs) and avoided damage estimates. It presents adaptation investment requirements, avoided deterioration costs, and net benefits by scenario and asset class. Demonstrates where adaptation delivers the strongest returns.
Section 3.5 – Impacts of Alternative Climate Futures and Emissions Pathways	This section compares the results of the primary SSP2-4.5 pathway under alternative warming scenarios (SSP1-2.6 and SSP3-7.0). It illustrates how cost projections vary with different climate futures.
Section 3.6 – Flood Adaptation	This section summarizes results from the high-level flood modelling stream, including projected flood damage to buildings and the estimated benefits and costs of structural flood-protection measures. It presents avoided damage, investment requirements, and regional variation in flood-related risk and adaptation performance.

3.1 Canada's Public Infrastructure in a Stable Climate (Baseline Scenario)

This section establishes the foundation for understanding Canada's public infrastructure by describing its current state and costs of maintaining assets under a stable climate. It provides the baseline against which future climate impacts and adaptation needs are measured.

3.1.1 Overview of Canada's Public Infrastructure

Using Statistics Canada's Core Infrastructure Survey (2022), the total value of public infrastructure in Canada exceeds $2,760B. The total infrastructure value in *Fair* condition or worse was assessed as $964B. For the purpose of this study, the infrastructure backlog refers to the cost to return to a good state of repair. This means that the costs of repairing our infrastructure represent approximately 35% of the total value. (See **Figure 3.1**). Statistics Canada estimated the infrastructure backlog, or the costs of repairing all infrastructure to be about $294B (Statistics Canada, 2025).

WSP's work with the FAO of Ontario demonstrated that the infrastructure backlog would be impacted by climate change. The difference in cost to return infrastructure to a state of good repair under a baseline scenario, compared to under climate change, is important as it signals the degree to which infrastructure investment may need to increase, to manage and operate infrastructure now and into the future.

Table 3-2 presents the distribution of total infrastructure value in Canada across the different categories of public organization. Most public infrastructure value in Canada, over 73%, is owned and managed by local and regional organizations. Provincial and territorial governments hold about 25%, while the federal share is just over 1%. This included most road networks, water and stormwater infrastructure, with each being particularly vulnerable to climate change impacts, such as increased precipitation, rising temperatures, and freeze-thaw cycles. These climate effects shorten asset lifespans, and increase the need for maintenance, upgrades, and replacements.

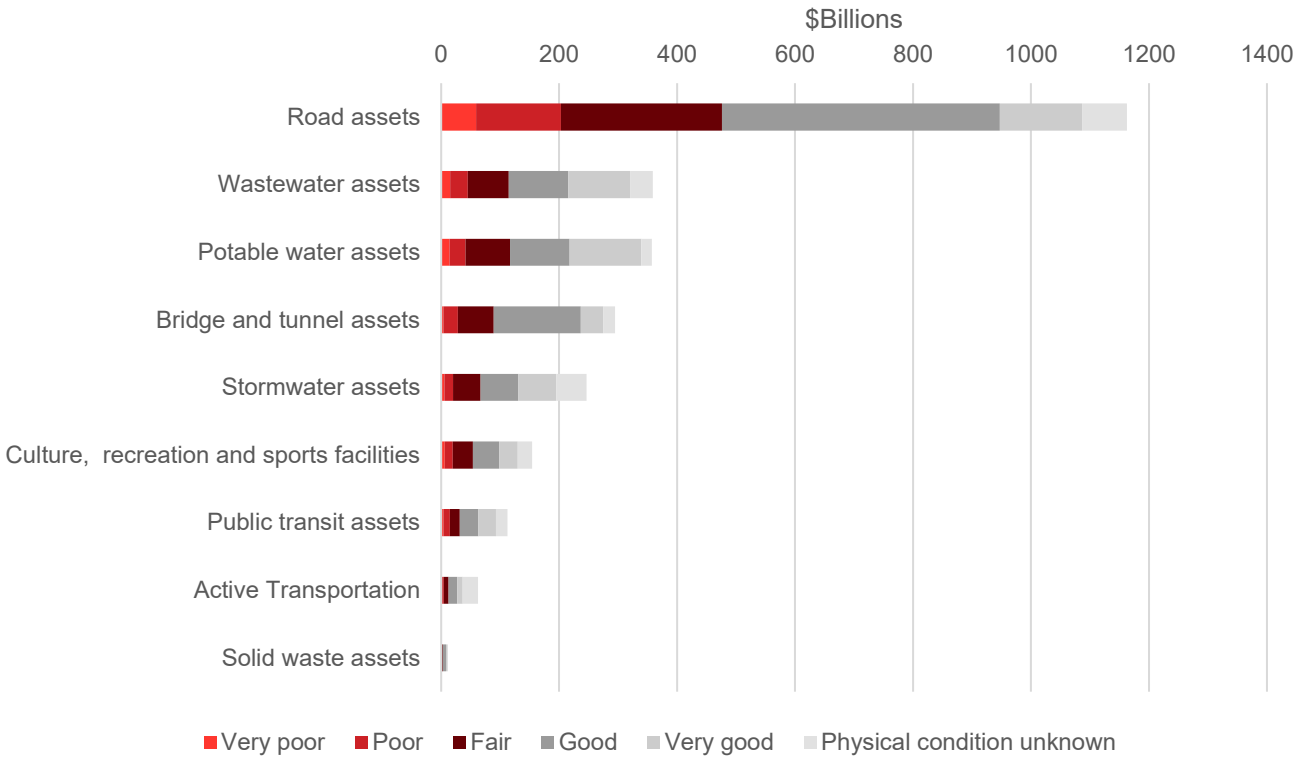

Figure 3.1: Estimated replacement value (in $B) of core public infrastructure assets in Canada (all public organizations) by condition and asset types

Given the proportion of assets in the public sector, municipalities will bear the largest share of the financial burden for climate adaptation. Provincial and territorial governments will also face significant costs, especially for roads and bridges.

As expected, when categorized by asset type, road networks dominate the national portfolio, representing roughly 42% of total value. Water-related systems, potable water, wastewater, and stormwater collectively contribute close to 35%. Bridges and tunnels comprise about 11%, while cultural, recreational, and sports facilities represent another 6%. In addition, public transit assets account for 4%, and active transportation infrastructure for 2%, with solid waste systems representing a very small fraction.

Ownership patterns vary significantly across these categories. Municipalities overwhelmingly manage water and wastewater systems, stormwater networks, and most cultural and recreational facilities. They also hold the majority of public transit and active transportation assets. In contrast, provinces and territories dominate the bridge and tunnel category and maintain a substantial share of road infrastructure. The federal government's involvement is limited to select numbers of strategic assets, comprising primarily bridges, tunnels, and certain cultural facilities.

Table 3.2: Distribution of total infrastructure value in Canada across different public organizations

	Federal Government	Provincial and Territorial Government	Local and Regional Government	Total
Road assets	0.3%	15.1%	26.9%	**42%**
Potable water assets	<0.1%	0.1%	12.9%	**13%**
Wastewater assets	<0.1%	<0.1%	13.0%	**13%**
Bridge and tunnel assets	0.6%	7.4%	2.8%	**11%**
Stormwater assets	<0.1%	1.3%	7.7%	**9%**
Culture, recreation, and sports facilities	0.4%	0.5%	4.6%	**6%**
Public transit assets	<0.1%	1.0%	3.1%	**4%**
Active Transportation	<0.1%	<0.1%	1.9%	**2%**
Solid waste assets	<0.1%	<0.1%	0.5%	**0%**
Total	**1.3%**	**25.36%**	**73.34%**	**100%**

Figure 3.2 presents the total replacement value of assets by period of construction, offering insight into the age distribution of infrastructure across regions. The data shows a significant proportion of assets (83%) built before modern climate-resilient standards were adopted (e.g. approximately and gradually after 2015), with older infrastructure dominating the stock in many areas.

This age profile has important implications for climate-related performance. Assets constructed before recent design updates were built to earlier standards that did not incorporate recent observations of extreme rainfall or higher temperatures. In addition, older assets have accumulated physical wear, which affects condition regardless of design era. The combined effect of lower performance and poorer overall condition contributes to the higher climate-related vulnerability observed in older infrastructure in the model results. Without targeted upgrades or retrofits, these aged systems will contribute to increased service disruptions, higher maintenance costs, because of greater exposure to environmental hazards over the next decade.

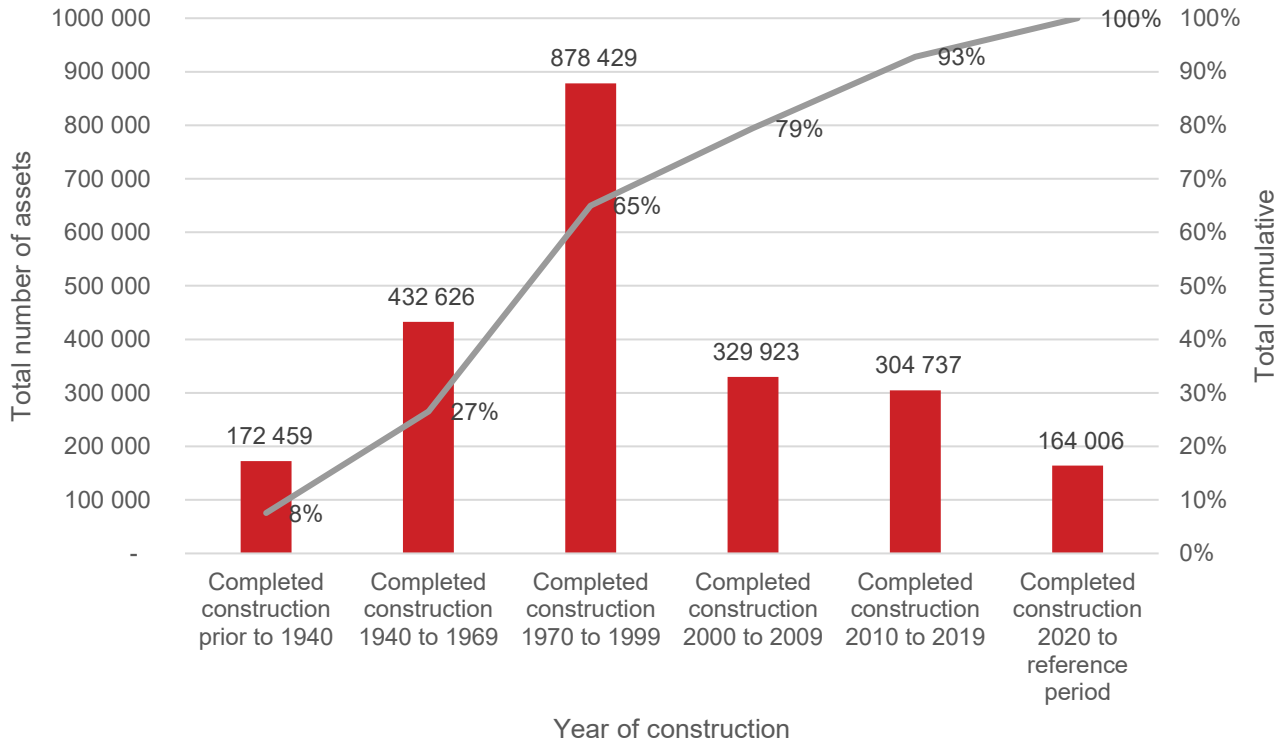

Figure 3.2: Total inventory of assets per period of construction

The distribution of infrastructure replacement value across Canadian provinces shown in **Figure 3.3** reveals significant disparities in both total asset value and known physical condition. Since the dataset included construction periods rather than exact years, we used the median year of each period to standardize the data and facilitate the analysis. Ontario and Quebec hold the largest shares, followed closely by Western Provinces. Quebec, while also having a high total value, displays a more balanced spread across known condition categories.

Smaller provinces and territories, such as Prince Edward Island, Yukon, and Nunavut, show minimal infrastructure value compared to total, with most of it also falling under "unknown condition."

The prevalence of assets in "poor" and "very poor" condition states across several provinces is attributed to several factors, including underinvestment in asset replacement, reliance on outdated construction standards (PIEVC Alliance and Climate Risk Institute, 2025), and limited lifecycle planning.

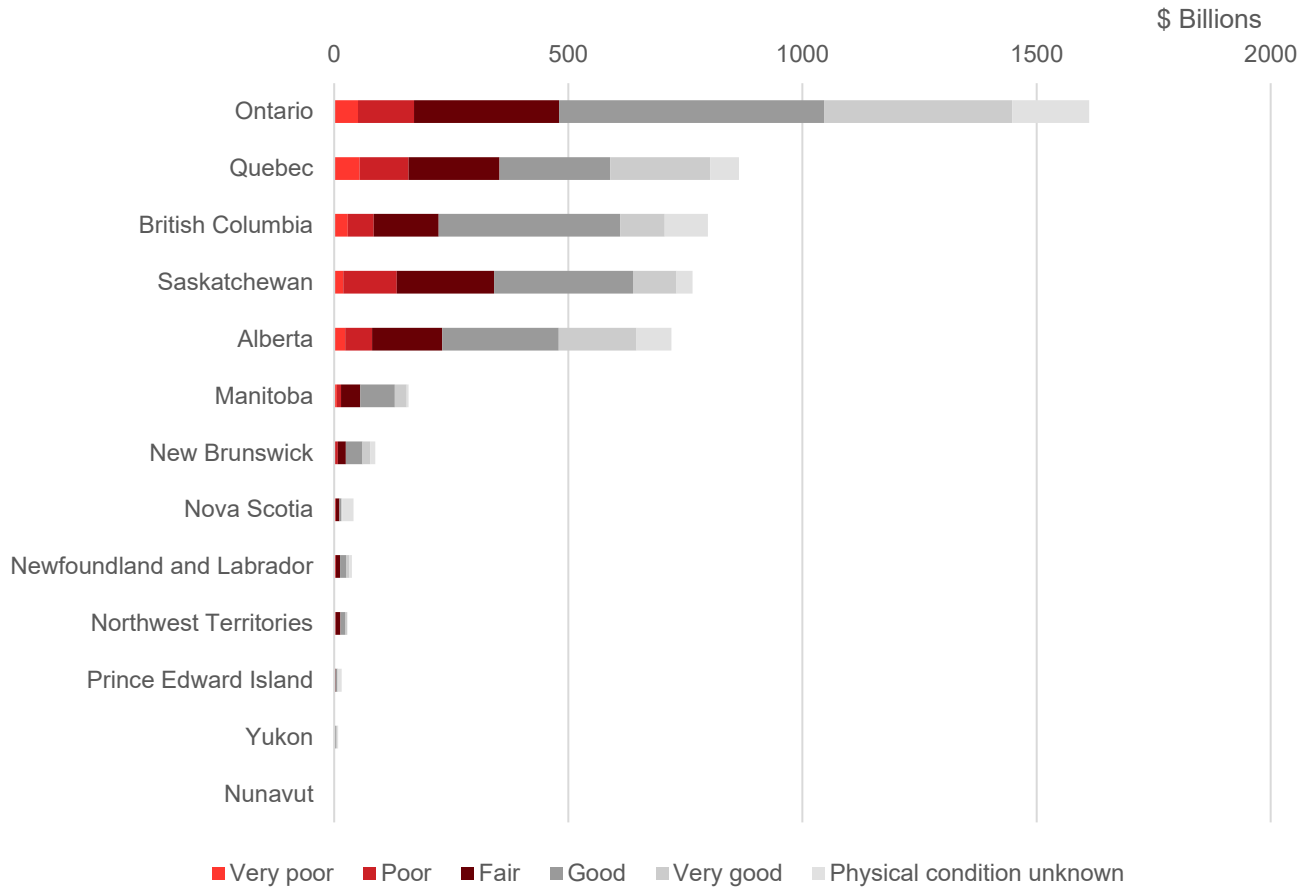

Figure 3.3: Total current replacement value per province and condition

3.1.2 Current State of Repair and Investment Gaps

Figure 3.4 presents a comparative overview of the physical condition of infrastructure assets across Canadian provinces and territories, measured by their share of total CRV. The chart categorizes asset conditions into six levels (ranging from "Very poor" to "Very good," plus an "Unknown" category) using a color-coded horizontal bar for each region. This categorization allows for a visual assessment of how well-maintained or deteriorated infrastructure is in each jurisdiction. It is important to note, however, that jurisdictions with a high proportion of assets classified as “Unknown”, such as Prince Edward Island, may have greater uncertainty in their condition profile. If a substantial share of these unknown assets were, in practice, in poor or very poor condition, overall condition distributions could shift materially. This uncertainty should be considered when interpreting provincial and territorial differences.

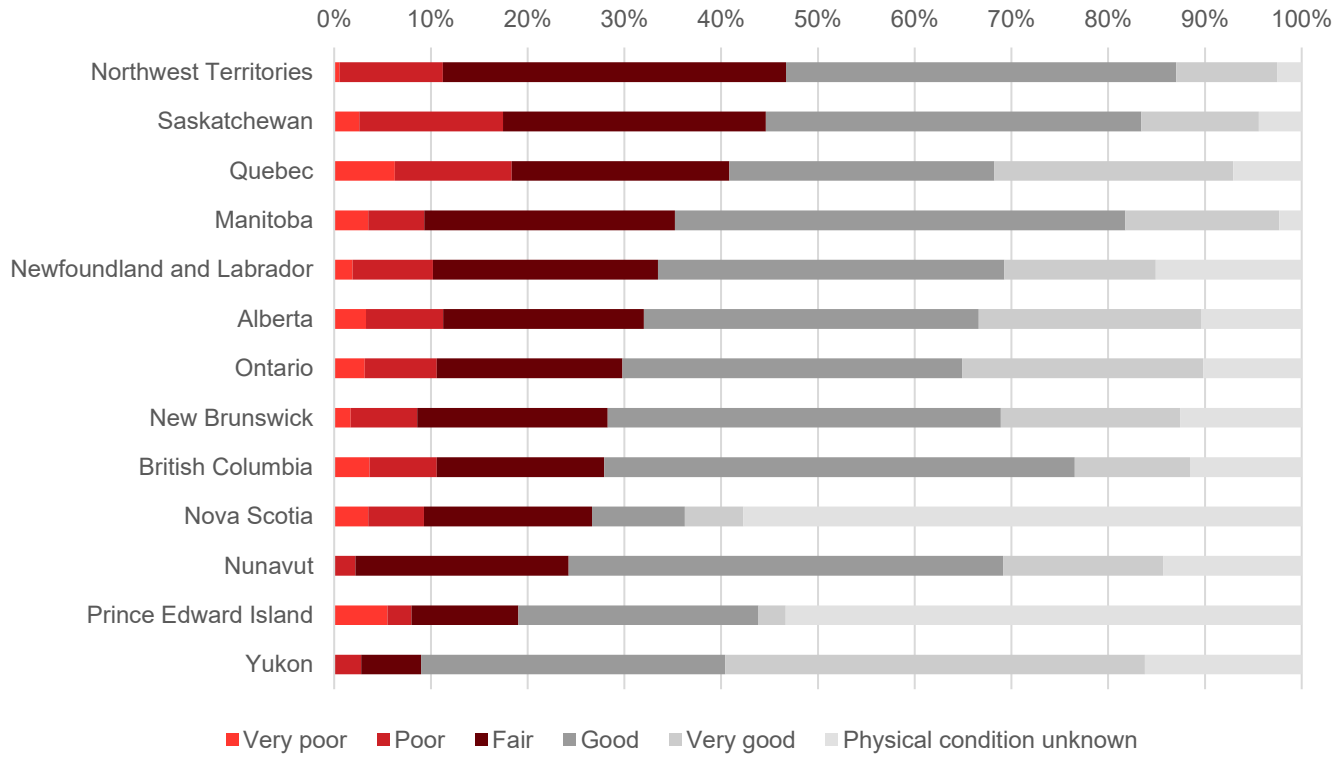

Figure 3.4: Condition proportionally weighted using current replacement value, by province

From the chart, clear differences emerge across jurisdictions. Saskatchewan and Quebec each show a comparatively larger share of assets in “Poor” condition, indicating a higher proportion of infrastructure approaching lower condition states relative to other provinces. Ontario has a more balanced distribution across the “Fair” and “Good” categories, while British Columbia shows one of the higher proportions of assets in “Good” condition. Some smaller jurisdictions, including Nova Scotia and Prince Edward Island, have distributions that lean more heavily toward “Fair” and “Poor” categories. These patterns illustrate the variation in reported infrastructure condition across provinces and territories, without suggesting any specific drivers behind these differences..

The analysis of public infrastructure assets from **Table 3.3** highlights significant disparities in both unit costs and asset distribution across categories. Local roads dominate in terms of total number of assets, with over 437,000 kilometers, reflecting their essential role in everyday mobility. Wastewater and potable water treatment facilities are among the most capital-intensive assets, with maximum unit costs exceeding $1.1B, underscoring their technical complexity and critical function.

Stormwater infrastructure, particularly open ditches and pipes, are present in large numbers across the country, while public transit assets stand out for their high unit costs, often in the tens of millions. Active transportation infrastructure, such as sidewalks and bikeways, are highly prevalent and supports sustainable urban mobility. In the cultural and recreational domain, parks are the most numerous assets,

while facilities like indoor pools and performing arts theatres represent higher-cost investments that contribute to community well-being.

The table below presents order-of-magnitude estimates of unit current replacement values. Note that the list of assets is non-exhaustive, as the categorization used by Statistics Canada for current replacement value and for stock is not entirely consistent. These estimates are derived from the ratio of the total current replacement value at the provincial level to the corresponding total asset stock. The results should be interpreted with caution and are intended solely to provide a broad indication of the relative magnitude of asset values.

Table 3.3: Unit current replacement value ($) and total number (unit or km) per infrastructure type

Road assets	Min ($)	Average ($)	Max ($)	Unit	Total Stock
Highways	120,335	136,6310	7,895,492	/km	4,126
Rural highways	22,511	1,047,611	33,333,333	/km	60,475
Arterial roads	153,333	1,410,713	7,730,061	/km	48,512
Collector roads	33,770	1,031,320	5,631,899	/km	97,867
Local roads	112,301	808,324	3,225,656	/km	437,712
Lanes and alleys	28,058	1,113,007	17,602,444	/km	16,165
Sanitary forcemains	40,016	1,013,005	12,291,869	/km	7,642
Sewer pipes	107,497	15,11,513	3,869,399	/km	103,516
Wastewater treatment facilities	3,174,603	45,513,515	1,152,953,586	/unit	1,079
Other non-linear wastewater facilities	5,285	917,491	25,000,000	/unit	12,517
Stormwater pipes	82,183	1,664,561	5,701,754	/km	90,719
Culverts (diameter less than 3 metres)	22,200	338,095	5,082,873	/km	16,881
Open ditches	875	30,671	2,383,447	/km	224,755
Stormwater Management facilities	53,419	838,163	17,289,377	/unit	1,1176
Stormwater drainage pump stations	18,182	2,293,656	8571,429	/unit	810
Linear potable water assets	101,183	1,322,537	6,338,031	/km	143,437
Water treatment facilities	190,476	1,3620,361	171,6953,125	/unit	2,313
Other non-linear potable water facilities	73,013	2,662,030	86,231,884	/unit	7,171
Total bridges	80,607	24,932,688	97,869,773	/unit	19,650
Arterial bridges	80,607	9,104,226	97,869,773	/unit	2,774
Highway bridges	200,000	1,170,8574	25,927,187	/unit	570
Local bridges	91,827	984,450	18,431,373	/unit	11,900
Collector bridges	128,452	1,997,950	50,000,000	/unit	3,201

Road assets	Min ($)	Average ($)	Max ($)	Unit	Total Stock
Rural highways bridges	99,206	1,137,488	3,5010,060	/unit	204
Tunnels	151,515	6,734,223	89,477,189	/unit	98
Culverts (diameter greater than or equal to 3 metres)	9,985	471,899	8,351,648	/unit	17,265
Transit-exclusive tracks and roads	1,800,000	6,770,017	26,479,751	/unit	707
Tunnels (transit exclusive only)	52,380,952	96,782,609	126,644,737	/unit	92
Bridges (transit exclusive only)	6,279,129	8,832,754	60,000,000	/unit	219
Other rolling stock assets	83,333	2,112,456	2,134,107	/unit	570
Passenger stations/terminals	100,000	15,527,140	472,916,667	/unit	301
Transit shelters	5,371	19,492	202,429	/unit	19454
Maintenance and storage facilities	26,6667	65,780,971	230202958	/unit	159
Footbridges	9,569	813,238	3,228,870	/unit	4003
Paved pathways (excludes bikeways)	5,833	440,298	1,552,414	/unit	10,681
Pedestrian tunnels	98,039	2,646,445	4,550,000	/unit	231
Sidewalks	36,873	301,180	2,637,658	/km	116,924
Total bikeways or cycleways	9,454	252,074	1,788,491	/unit	21,717
Trails (non-paved) (in kilometres)	NA	NA	NA	/unit	NA
Community centres (senior and youth centres)	112,233	3,892,626	36,687,631	/unit	4,425
Indoor pools	200,000	16,584,939	60,000,000	/unit	621
Total Arts and culture facilities	100,000	34,144,739	121,400,000	/unit	3,391
Art galleries	217,014	9,000,015	101,500,000	/unit	198
Indigenous culture facilities	100,000	1,966,504	10,000,000	/unit	21
Libraries	130,435	4,562,636	41,487,686	/unit	2,108
Museums and archives	100,000	3,425,197	40,050,505	/unit	783
Performing arts theatres	300,000	15,190,387	121,400,000	/unit	281
Total Ice facilities	782,779	46,334,930	123,550,000	/unit	2,144
Curling building	877,193	4,859,149	37,500,000	/unit	524
Indoor ice arenas, excluding performance/spectator (1,000 plus seats)	782,779	13,833,941	57,564,590	/unit	1,366
Indoor ice arenas, performance/spectator (1,000 plus seats)	1,001,001	27,641,840	123,550,000	/unit	254
Multi-purpose facilities, not elsewhere classified	172,414	2,370,897	30,158,730	/unit	1,528
Multi-purpose sports centre	200,000	2,4420,829	100,113,636	/unit	363
Total outdoor facilities	2,778	1,153,665	50,505,051	/unit	50,470
Other outdoor sports facilities	24,655	472,455	50,505,051	/unit	6,231
Outdoor specialty areas (off-leash dog parks, skateparks)	12,750	297,071	9,817,814	/unit	3,451
Parks (sports fields, children's parks, nature parks)	2,778	384,138	1,251,0936	/unit	40788

Road assets	Min ($)	Average ($)	Max ($)	Unit	Total Stock
Total waste disposal assets	NA	NA	NA	/unit	NA
Transfer station assets	54,795	1,092,715	7,230,7692	/unit	1,059
Total waste diversion assets	NA	NA	NA	/unit	NA

3.1.3 Maintaining and Operating Public Infrastructure in a Stable Climate

Before assessing the future impacts of climate change and the value of adaptation, it was essential to understand the current investment need of Canada's public infrastructure under stable climate conditions. The baseline scenario provided a reference point for the cost to maintain, renew, and operate infrastructure, and was based on today the infrastructure degradation model for the 1991-2020 baseline period. This scenario worked to highlight existing investment gaps, asset vulnerabilities, and regional disparities, and served as the foundation for comparing the additional risks and costs introduced by climate change. It provided the baseline against which future climate impacts and adaptation needs are measured.

The baseline analysis revealed a consistent pattern: actual investment in replacement and maintenance is significantly short of what is required to keep assets in a state of good repair.

Table 3.4 summarizes the national picture by asset type. The first column provides an overview of the estimated replacement value of each asset type across the country. Column two outlines reported 2022 annual replacement expenditures from the Core Public Infrastructure Survey which are the funds spent on the rehabilitation, reconstruction, or replacement of assets, including investments that improve performance or extend service life. Column three outlines the required annual replacement budget to maintain assets in a state of good repair, from the CPIS – showing the disparity between needs and actual spending. The required renewal budget represents the capital investment needed to rehabilitate or replace existing public infrastructure assets to maintain them in good physical condition. Columns 4 and 5 then highlight the projected replacement expenditures and the projected O&M – these are based on WSP's asset deterioration model. The actual replacement expenditures and projected replacement expenditures are displayed to illustrate the model output against the actual data. O&M projected data are also displayed, but cannot be compared to actual data, since this information is not collected by the CPIS.

In terms of results, public transit assets stood out with the highest replacement requirement (17%). Road infrastructure, with an estimated replacement value of $1.16T, illustrates a consistent pattern across asset classes: current replacement expenditures (1.0% of estimated replacement value) are lower than the required replacement budget (9%), indicating a gap between existing spending levels and the amount of infrastructure currently assessed as needing renewal. Water-related assets (potable water and wastewater) also showed required replacement budgets of 11–12% of current replacement value, but actual spending is only 1.2–1.3%. Cultural, recreational, and sports facilities, while lower in total value, have high operating and maintenance costs (1.4%) and a replacement need of 12%. Solid waste infrastructure, though modest in scale, in comparison to other asset types, showed a relatively high actual

replacement expenditure rate (5.8%), possibly reflecting better alignment between spending and needs. Note that the required replacement budget is the amount of assets below the state of good repair and should not be interpreted as an annualized rate of replacement.

Table 3.4: Current annual costs of maintaining infrastructure nationally per asset type (stable climate)

Assets	Estimated replacement value	Actual replacement expenditures[1]		Required replacement budget[2]		Projected Replacement Expenditures		Projected O&M[3]	
	$B	$M	% CRV	$M	% CRV	$M	% CRV	$M	% CRV
Road assets	1,162	11,039	1.0%	107,006	9%	24,005	2.1%	15,421	1.3%
Wastewater assets	359	4,238	1.2%	38,345	11%	4,452	1.2%	4,168	1.2%
Potable water assets	357	4,294	1.2%	41,197	12%	4 ,140	1.2%	4,240	1.2%
Bridge and tunnel assets	295	1,609	0.5%	21,474	7%	3,627	1.2%	2,738	0.9%
Stormwater assets	247	1,652	0.7%	31,949	13%	2,534	1.0%	2,672	1.1%
Culture, recreation and sports facilities	154	2,230	1.4%	18,008	12%	2,627	1.7%	2,146	1.4%
Public transit assets	112	3,287	2.9%	19,483	17%	2,557	2.3%	1,562	1.4%
Solid waste assets	13	755	5.8%	1,372	11%	374	2.9%	15,3	1.2%
Total	**2,698 $**	**29,104**	**1.1%**	**278, 834**	**10.3%**	**44,315**	**1.6%**	**33,100**	**1.2%**

[1] Actual replacement expenditures are the funds spent on the rehabilitation, reconstruction, or replacement of assets, including investments that improve performance or extend service life Ref: Statistics Canada Core Public Infrastructure Survey (2022)

[2] A required replacement budget is the capital investment needed to rehabilitate, reconstruct, or replace assets to a "good" physical condition Ref: Statistics Canada Core Public Infrastructure Survey (2022)

[3] Projected O&M are calculated by attributing an O&M rate, adapted from aspects of the FAO of Ontario model to the Statistics Canada terminology.

Table 3.5 presents the current annual costs of maintaining public infrastructure across Canada's provinces and territories, under stable climate conditions. This table uses the same data as **Table 3.4**, but disaggregates the results by geography rather than presenting them by asset type.

Ontario continues to lead with the highest estimated replacement value ($795B) and a required annual replacement budget of 10% of estimated replacement value. However, actual replacement spending in Ontario is only 1.3% of replacement value, highlighting a substantial shortfall. Quebec, with $434B of estimated replacement value, faces an even greater replacement need at 16%, yet current expenditure remains at just 1.7%. In British Columbia and Alberta, required replacement budgets are lower (5–7%), but actual spending (0.6% and 1.0%, respectively) again falls well below what is needed.

Smaller jurisdictions face unique challenges. Nova Scotia stood out with a required replacement budget of 70% estimated replacement value (by far the highest in the country) while actual spending is 3.1%. Nunavut, despite its modest asset base, also showed a required replacement budget of 9%, and actual spending of 4.0%. The Northwest Territories faces a gap, with a need of 48% replacement value, but 0.4% of estimated replacement value is being spent on replacements.

Nationally, the pattern is clear: actual annual replacement expenditures average just 1.1% of replacement value, compared to a required 11%. These figures underscore a systemic underfunding of infrastructure replacement across all regions.

As the CPIS does not provide empirical data on O&M (Operations and Maintenance), an annual rate of O&M, in % of total current replacement value was applied, according asset type. Projected O&M costs were estimated as 1.2% of replacement value.

The updated annual perspective provided in **Table 3.5** highlights a substantial gap between current replacement spending and the level of investment required to bring assets to a state of good repair under stable-climate conditions. While this comparison illustrates the scale of the backlog, it is important to recognize that a steady-state funding level that maintains assets in a balanced condition profile is typically lower than the full state-of-good-repair requirement; in practice, sustainable long-term funding needs may be closer to a fraction of the backlog estimate rather than its full value.

Addressing these gaps reduces risk because assets in better physical condition are less susceptible to damage from heat, heavy rainfall, and flooding than assets that have already experienced significant wear. Older or deteriorated systems are more likely to experience service interruptions when exposed to extreme weather, whereas assets in a state of good repair have greater remaining capacity to manage additional climate related stresses. Bringing assets up to baseline condition provides a consistent starting point for incorporating climate resilient design updates during renewal or replacement activities, as these upgrades are typically integrated when major work is already taking place.

Table 3.5: Current annual costs of maintaining infrastructure nationally per province (stable climate)

Province/ Territory	Estimated Replacement Value	Actual Replacement Expenditures[1]		Required Replacement Budget[2]		Projected Replacement Expenditures		Projected O&M	
	$B	$M	% CRV	$M	% CRV	$M	% CRV	$M	% CRV
Ontario	865	11,268	1.3%	112,712	10%,	12,066	1.5%	9,645	1.2%
Quebec	472	8,057	1.7%	9,862	16%	6,495	1.5%	5,230	1.2%
British Columbia	424	2,554	0.6%	27,671	5%	6,261	1.6%	4,912	1.3%
Saskatchewan	339	1,705	0.4%	44,340	8%	8,010	2.0%	5,106	1.3%
Alberta	390	3,915	1.0%	35,641	7%	5,952	1.7%	4,308	1.2%
Manitoba	91	1,187	1.3%	11,875	10%	1,458	1.7%	1,014	1.2%
New Brunswick	48	524	1.1%	6,811	11%	747	1.7%	536	1.2%
Newfoundland and Labrador	23	347	1.5%	4,504	15%	398	1.9%	293	1.4%
Northwest Territories	15	61	0.4%	9,553	48%	304	2.2%	196	1.4%
Nova Scotia	17	525	3.1%	15,408	70%	274	1.8%	195	1.3%
Prince Edward Island	8	38	0.5%	298	3%	128	1.8%	86	1.2%
Yukon	4	28	0.7%	207	4%	87	2.4%	51	1.4%

Province/ Territory	Estimated Replacement Value	Actual Replacement Expenditures[1]		Required Replacement Budget[2]		Projected Replacement Expenditures		Projected O&M	
	$B	$M	% CRV	$M	% CRV	$M	% CRV	$M	% CRV
Nunavut	<1	19	4.0%	54	9%	8	1.9%	5	1.3%
Canada	**2,698 $**	**30,227**	**1.1%**	**278,935**	**10.3%**	**44,315**	**1.6%**	**33,100**	**1.2%**

[1] Actual replacement expenditures are the funds spent on the rehabilitation, reconstruction, or replacement of assets, including investments that improve performance or extend service life (Ref: CPIS, 2022)

[2] A required replacement budget is the capital investment needed to rehabilitate, reconstruct, or replace assets to a "good" physical condition (Ref: CPIS, 2022)

[3] Projected O&M are calculated by attributing an O&M rate, from selected aspects the FAO of Ontario model to the Statistics Canada terminology

Under the stable-climate baseline, the deterioration model produces long-run projections of annual replacement, repair, and O&M needs for all public infrastructure assets. **Table 3.6** summarizes these modelled annual costs for three standard time horizons (2011–2040, 2041–2070, and 2071–2100), which are the same climate-data periods used throughout the report. Although this section focuses on stable-climate conditions, the use of these time windows allows the baseline results to be compared directly with later sections that incorporate climate change. The values in Table 3-6 therefore represent the total annual cost of maintaining, repairing, and renewing infrastructure under a stable climate, aggregated by level of government, and do not include any climate-related deterioration.

These results show a consistent upward trend in lifecycle needs over the century due to Canada's aging infrastructure profile and long replacement cycles. Local and regional governments carry most of these costs because they own most of the national asset base. Provincial and territorial governments account for roughly a quarter of annual needs, while federal costs remain comparatively small. Total annual baseline costs increase from $97.55B in the early period to $119.59B by end-of-century.

Table 3.6: Shares of average annual costs to maintain infrastructure for 2025, 2055, and 2085 (millions/year) (stable climate)[1]

	2011-2040 ($M/Yr)	2041-2070 ($M/Yr)	2071-2100 ($M/Yr)	2025-2100 ($M/Yr)
Federal Government	1,853	2,133	2,272	2,129
Provincial and Territorial	25,070	28,850	30,736	28,799
Local and Regional	70,624	81,275	86,586	81,129
Total	**97,548**	**112,258**	**119,594**	**112,057**

[1] The distribution of costs across levels of government was calculated by attributing average costs to the current value of infrastructure. However, the results may not fully capture disparities arising from level-specific factors, such as differences in the year of construction and the useful service life of assets.

3.2 The Costs of Climate Change for Canada's Public Infrastructure

This section presents projections of how climate change will alter the costs and performance of Canada's public infrastructure, if no adaptation measures are taken. The analysis quantifies the additional burden

from increased climate hazards, accelerated asset deterioration, and rising O&M, rehabilitation, and replacement costs.

The Δp values described in **Section 2.4** represent the relative change in costs associated with different climate scenarios (primarily SSP2-4.5), time horizons (2025, 2055, 2085), and climate hazards, specifically extreme rainfall and extreme heat.

3.2.1 National and Regional Climate Change Cost Projections

Climate change will place increasing additional cost pressure on Canada's public infrastructure owners in the absence of adaptation. Even if assets were to be maintained and renewed according to current standards, higher temperatures, more intense rainfall, and accelerating degradation will increase the frequency and cost of required interventions.

Table 3.7 illustrates how these climate-driven pressures compound baseline infrastructure costs over time. Under the no-adaptation scenario, climate change was show to add$8.8B per year to annual infrastructure spending in 2025. By mid-century, these additional costs rise to $14.3B per year, reflecting the growing influence of climate-related impacts. By 2085, climate-driven costs reach $19. B annually, nearly doubling relative to today. When combined with baseline spending needs, total annual infrastructure expenditures increased from $106B in 2025 to $127B in 2055 and almost $139B by 2085. Overall, the results confirm that climate change significantly elevates the long-term cost of maintaining and renewing public infrastructure.

Table 3.7: Average annual infrastructure costs and climate-driven costs without adaptation

	2011-2040 ($B)	2041-2070 ($B)	2071-2100 ($B)	2025-2100 ($B)
Baseline costs- no climate change scenario	97.55	112.26	119.59	112.06
Additional climate-driven costs – no adaptation scenario	8.84	14.27	19.38	15.15
Total	**106.39**	**126.53**	**138.97**	**127.20**

Table 3.8 summarizes the projected annual climate-related costs for public infrastructure by jurisdiction, under the no-adaptation scenario, which assumes assets continue to be replaced to today's standards upon replacement. It highlights both the absolute and relative scale of impacts, as well as the asset types most affected in each region.

All provinces and territories experience rising costs, though the magnitude and timing vary depending on local climate hazards, asset age and condition, and historical investment patterns. Ontario and Quebec show high absolute climate-related costs by century end ($6.4B and $3.2B respectively), reflecting both the scale of their assets and growing climate exposure. These costs represent a 20% and 18% increase, respectively, over the baseline scenario. In contrast, smaller jurisdictions like Yukon and the Northwest Territories exhibit lower absolute costs but face disproportionately high burdens, with costs reaching 17% and 31% increase by century end compared to the baseline scenario. These projections highlight not only the scale of the financial challenge, but also the uneven distribution of climate impacts across the country. Projected Cost Increase, in % of total annual costs, between 2025 and 2085 by provinces and territories is presented in **Table 5-1** in **Appendix A**.

Nationally, the most impacted asset type is road infrastructure, consistently appearing across jurisdictions as a key area of concern. Key cost drivers include the combined effects of heat and extreme rainfall on roads, which accelerate material fatigue, shorten service life, and increase the frequency of maintenance and rehabilitation, particularly in jurisdictions with extensive road networks.

Costs are also driven by extreme rainfall–related operating and damage pressures on stormwater and wastewater systems, including higher treatment demands, increased overflow risk, and flood-related repairs, especially in large urban systems.

Table 3.8: Projected incremental annual climate-related costs for public infrastructure (no adaptation scenario)

Jurisdiction	Projected Climate Change Annual Cost ($M)				% Annual Cost Increase Over Baseline				Key Asset Types Most Impacted
	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100	
Newfoundland and Labrador	34	64	106	74	6%	9%	13%	10%	Road and Wastewater assets
Prince Edward Island	23	53	51	46	6%	13%	13%	11%	Road assets
Nova Scotia	31	83	97	77	6%	13%	14%	12%	Road and Potable water assets
New Brunswick	75	199	207	176	5%	12%	12%	11%	Road and bridge and tunnel assets
Quebec	1,378	2,256	3,151	2,424	10%	14%	18%	14%	Road and wastewater assets
Ontario	2,781	4,394	6,447	4,865	11%	15%	20%	16%	Road and wastewater assets
Manitoba	357	326	530	413	10%	8%	13%	11%	Road and wastewater assets
Saskatchewan	1,903	1,457	2,388	1,918	10%	7%	11%	9%	Road and Culture, recreation and sports facilities assets
Alberta	1,157	1,360	2,112	1,614	9%	10%	14%	11%	Road and wastewater assets
British Columbia	587	2,262	2,328	1,935	4%	13%	13%	11%	Road, bridges and tunnel assets
Yukon	7	19	25	19	7%	14%	17%	14%	Bridges, tunnel, and road assets
Northwest Territories	76	159	247	176	11%	21%	31%	23%	Road, bridges and tunnel assets
Nunavut	0	4	6	4	2%	15%	22%	15%	Road assets
Canada	8,842	14,273	19,378	15,145	9%	13%	16%	13%	Road and wastewater assets

3.2.2 Distribution of Costs Across Levels of Government

Building on the national and regional estimates, this section presents how climate-related costs are distributed across levels of government, recognizing that responsibilities for infrastructure ownership, operation, and maintenance are not uniform.

Table 3.9 shows projected climate-related costs by level of government and asset type over time, providing insight into which orders of government are likely to bear the greatest burden as climate risks intensify and

how this burden evolves through 2025, 2055, and 2085. The proportion of projected annual incremental cost borne by different levels of government is provided in **Table 5-2** in **Appendix A**.

As with the baseline scenario, projected incremental climate-related costs are distributed unevenly across levels of government in the no adaptation scenario. National annual climate-related costs rise from $8.8B per year in 2025 to $19.4B per year in 2085, with the burden falling predominantly on local and regional governments. By century end municipalities bear 72% of total climate-related infrastructure costs – about $14.02B per year. This burden reflects the concentration of climate-driven costs in municipal assets, particularly water, wastewater, and public transit systems. Provincial and territorial governments owned infrastructure will account for approximately 33% of climate-related costs, or about $5B annually by end of century, while federally owned infrastructure will account for roughly 2%, or $0.31B per year.

Climate change impacts on road assets were identified as the largest cost driver across all government levels, though the road assets' share declines over time as water and wastewater pressures intensify, especially for municipalities. For provincial and territorial governments, roads costs remain dominant with bridge and tunnel costs become increasingly important (from 12% in 2025 to 21% by end of century), while at the federal level, bridge/tunnel and culture, recreation, and sports assets account for the largest and rising shares. Overall, costs escalate sharply over time, with municipalities bearing the heaviest load with a gradual shift toward water-related asset spend.

Table 3.9: Projected incremental cost borne by different levels of government (no adaptation – annual, $m/ year)[1]

Asset Type	Federal Government				Provincial and Territorial Government				Local and Regional Government			
	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100
Road assets	41	54	70	57	2,061	2,706	3,527	2894	3,671	4,820	6,283	5,156
Potable water assets	6	12	17	13	6	12	17	13	742	1,543	2,157	1,617
Wastewater assets	8	15	22	17	8	15	22	17	1,007	1,996	2,914	2,150
Bridge and tunnel assets	25	65	86	65	308	798	1,062	799	117	302	402	302
Stormwater assets	4	8	11	8	47	104	138	106	280	617	820	626
Culture. recreation. and sports facilities	21	45	75	52	27	56	94	65	245	520	861	597
Public transit assets	5	12	17	12	45	122	167	123	140	377	517	382
Solid waste assets	4	10	14	11	4	10	14	11	22	52	71	53
Total	113	222	312	234	2,506	3,824	5,041	4,027	6,223	10,228	14,025	10,884

[1] The distribution of costs across levels of government was calculated by attributing average costs to the current value of infrastructure. However, the results may not fully capture disparities arising from level-specific factors, such as differences in the year of construction and the useful service life of assets

3.2.3 Asset-Specific Costs

Analysis by asset type under the no adaptation scenario shows that climate change will drive substantial increases in annual costs for Canada's public infrastructure, with the scale of impact varying widely across asset types.

Table 3.10 summarizes the projected annual climate-related costs for public infrastructure by asset types, under the no-adaptation scenario. It highlights both the absolute and relative scale of climate-related impacts. Results show that climate-related costs intensify across all asset types from 2025 to 2085, with the steepest burdens on transportation system – including road, public transit, and bridge and tunnel assets. Transportation system accounts for $6.41B of climate-related cost annually in 2025, increasing to $12.13B annually by end of century. This represents between 63% and 73% of total climate-related cost to public infrastructure between 2025 and 2100, and a 14% increase in costs by end of century compared to the baseline scenario. This reflects their broad exposure and sensitivity to climate-driven hazards such as temperature fluctuations and precipitation.

Within the transportation system group, impacts are uneven across asset types. Road assets dominate absolute climate-related costs (from $5.77B to $9.88B between 2025 and 2085) with a moderate percentage increase (8.8% to 13.7%). Bridges and tunnels grow faster relative to baseline (18.4% to 29.8%) accounting for $0.45B to $1.55B by end of century. Climate-related cost for public transit remains the smallest transportation component ($0.70B by end of century) and shows a more modest percentage rise compared to baseline (3.6% to 10.6% by 2085). This indicates steady but comparatively lower pressure on public transit assets than on bridges and tunnels; consequently, while roads continue to represent the largest share of transportation costs in absolute terms, their relative share declines over time as climate-related costs for bridges and tunnels increase more rapidly.

Water systems also face increasing climate-related costs. Collectively, climate costs related to potable, wastewater and stormwater assets climb from $2.10B in 2025 to $6.12B by 2085, nearly tripling. Wastewater assets are the largest contributor ($1.02B in 2025 to $2.96B in 2085) with high percentage increases compared to baseline (between 12.1% and 18.6%). Climate-related costs for potable water nearly triples (from $0.75B to $2.19B) and more than doubles in percentage terms (6.1% → 15.3%), while stormwater costs rise from $0.33B to $0.97B by end of century, with a sharp percentage increase compared to baseline (4.7% to 11.9%).

Buildings account for approximately $1.0B per year, or about 5.0%, of total climate-related infrastructure costs by end of century, representing an increase of nearly 12.0% compared to baseline.

By end of century, transportation accounts for roughly twice the water-system total, but both groups show clear, sustained escalation, underscoring the need for targeted adaptation across roads and fixed structures as well as accelerated upgrades to wastewater, potable, and stormwater systems.

Table 3.10: Projected annual incremental costs by asset type (Canada, no adaptation scenario, with climate change)

Asset type	Projected Climate Change Annual Cost ($B)				% Annual Cost Increase Over Baseline			
	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100
Road assets	5.77	7.58	9.88	8.11	8.8%	10.6%	13.7%	11.4%
Bridge and tunnel assets	0.45	1.16	1.55	1.17	6.1%	12.4%	15.3%	12.2%
Public transit assets	0.19	0.51	0.70	0.52	3.6%	7.4%	10.6%	7.8%
Wastewater assets	1.02	2.03	2.96	2.18	21.7%	35.0%	37.8%	33.3%
Potable water assets	0.75	1.57	2.19	1.64	18.4%	30.5%	29.8%	27.6%
Stormwater assets	0.33	0.73	0.97	0.74	12.1%	17.8%	18.6%	16.9%
Culture, recreation and sports facilities	0.29	0.62	1.03	0.71	4.7%	8.2%	11.9%	8.9%
Solid waste assets	0.03	0.07	0.10	0.07	1.9%	4.2%	5.7%	4.3%
Total	**8.84**	**14.27**	**19.38**	**15.15**	**9.1%**	**12.7%**	**16.2%**	**13.3%**

3.3 The Costs of Adapting Public Infrastructure – Reactive Adaptation and Proactive Adaptation

This analysis in this section is used to compare the results of the no adaptation, reactive adaptation, and proactive adaptation scenarios, showing how each approach alters deterioration patterns and long-term lifecycle costs. It highlights how the timing of upgrades affects infrastructure performance, the pace at which assets become climate resilient, and the overall cost implications for governments.

3.3.1 National and Regional Cost Impacts of Adaptation

Proactive adaptation, which involves upgrading infrastructure before it reaches the end of its useful life or major rehabilitation point, can deliver greater long-term benefits than reactive adaptation, which implements upgrades only at the time of asset replacement or failure. While proactive strategies require higher upfront investment, they yield substantial cost savings across most asset types by 2085.

Table 3.11 presents the national average annual climate-related costs for public infrastructure under three adaptation scenarios (no adaptation, reactive adaptation, and proactive adaptation), expressed as a share of 2022 spending. In this context, 2022 spending refers to the estimated annual amount required to operate, maintain, and replace public infrastructure under stable climate conditions (see Section 3.1.3). Expressing climate-related costs as a proportion of this baseline shows what portion of today's system-wide spending would be absorbed by climate-related damage and adaptation-related activities in each scenario. These values represent the combined effect of climate-driven infrastructure costs and the additional costs associated with implementing adaptation measures under each scenario. Presenting the results in this way highlights how the financial burden associated with climate impacts changes relative to the level of investment already needed to maintain infrastructure today, including the observation that proactive adaptation is associated with a smaller share of this spending over the long term compared with the no-adaptation and reactive scenarios. These figures, shown for the periods 2011–2040, 2041–2070,

and 2071–2100 under a medium-emissions pathway, illustrate how different adaptation approaches influence long-term climate-related expenditure patterns.

The results show that national average annual climate-related costs - including both climate-related costs and adaptation costs for public infrastructure - are projected to rise substantially under all scenarios. Without adaptation, these costs increase from 9.1% of 2022 spending over the 2011-2041 period to 19.9% by 2071-2100, representing $19.38B. Reactive adaptation can moderate these increases, reducing costs to 9.9% of 2022 spending by 2071-2100, representing $9.70B. Proactive adaptation delivers the greatest cost savings, limiting annual climate-related costs to 5.1% of 2022 spending by 2071-2100. These findings highlight the significant long-term financial benefits of early and strategic adaptation investments, compared to a reactive or no-adaptation approach.

Table 3.11: National annual average climate-related costs for each scenario as a share of 2022 spending (medium-emissions scenario)

	2011-2040		2041-2070		2071-2100	
	%	$B/year	%	$B/year	%	$B/year
No Adaptation	9.1%	8.84	14.6%	14.27	19.9%	19.38
Reactive Adaptation	9.6%	9.41	12.4%	12.12	9.9%	9.70
Proactive Adaptation	9.2%	8.98	6.9%	6.75	5.1%	4.95

When considering the average annual impact over the period from 2025 to 2100 (**Table 3.12**), the economic case for adaptation remains clear. Under a no adaptation scenario, average annual national climate-related infrastructure costs are projected to reach $15.15B. Both reactive and proactive adaptation strategies offer meaningful reductions in these costs. Reactive adaptation lowers average annual costs to $10.59B (a 30% reduction compared to no adaptation), while proactive adaptation reduces costs to $6.51B (a 57% reduction). These results underscore that, while adaptation cannot eliminate all climate-related costs, early and strategic investments can generate significant long-term savings and help limit the financial risks associated with climate change.

Table 3.12: Average annual national incremental climate cost by scenario (2025–2100)

Scenario	Average Annual Cost ($B/year)	% Change vs. No Adaptation
No Adaptation	15.15	-
Reactive Adaptation	10.59	-30%
Proactive Adaptation	6.51	-57%

Table 3.13 decomposes average annual climate-related spending into climate-related damages and adaptation investment for the three adaptation scenarios. Under no adaptation, damages and total

spending rise steeply over time. Reactive adaptation introduces growing investment needs and reduces damage only gradually, producing a clear mid-century peak in total spending before easing by 2085, yet remaining higher than proactive in every year. Proactive adaptation front-loads investment, driving much larger damage reductions and yielding the lowest total spending with a steady decline from 2025 to 2085. While proactive totals are roughly on par with (or slightly above) no-adaptation in 2025, they become dramatically lower by mid-century and late-century—about 45% lower than reactive in 2055 and roughly 50% lower than reactive and 75% lower than no adaptation by 2085—showing that earlier, planned upgrades minimize long-run costs and avoid the mid-century spike.

Table 3.13: Annual climate-related damage and adaptation investment by adaptation scenario

	Climate-related damage to infrastructure				Adaptation investment				Total spending			
	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100
No Adaptation	8,842	14,273	19,378	15,145	0	0	0	0	8,842	14,273	19,378	15,145
Reactive Adaptation	8,644	9,445	5,959	7,900	765	2,679	3 737	2,694	9,409	12,124	9,696	10,594
Proactive Adaptation	5,911	2,044	858	2,390	3,072	4,704	4,090	4,118	8,983	6,748	4,948	6,508

The benefits of proactive adaptation are evident across provinces and territories. **Table 3.14** presents average annual infrastructure spending by province and territory, including both climate-related costs and adaptation costs, under three scenarios, compared with a stable climate baseline for the years 2025, 2055, and 2085. Breakdowns of average annual climate-related spending into climate-related damage and adaptation investment for the reactive and proactive adaptation scenarios by provinces and territories are available in **Table 5-5** and **Table 5-6** of **Appendix A**.

The table shows that climate change increases infrastructure costs across Canada, with reactive adaptation generally resulting in higher annual expenditures than proactive approaches. In nearly every jurisdiction and period, proactive adaptation leads to notable savings, particularly in 2055 when climate impacts and asset vulnerabilities peak. Nationally, proactive adaptation yields approximately 5% savings in 2025 compared to reactive adaptation, rising to nearly 44% by mid-century, before stabilizing around 49% in 2085.

Table 3.14 outlines the regional variation for average annual spending by scenario and province across the three scenarios

Table 3.14: Average annual spending by scenario and province – compared to no climate change baseline[1]

Province/ Territory	No Adaptation ($M)				Reactive ($M)				Proactive ($M)				% Savings (Proactive vs. Reactive)			
	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100
Newfoundland and Labrador	34	64	106	74	35	60	78	62	41	44	31	38	-18%	28%	61%	39%
Prince Edward Island	23	53	51	46	26	39	16	27	22	17	14	17	16%	57%	13%	38%
Nova Scotia	31	83	97	77	34	65	43	50	33	42	30	35	5%	35%	30%	29%
New Brunswick	75	199	207	176	84	154	107	121	83	93	55	76	1%	40%	49%	37%
Quebec	1378	2256	3151	2424	1444	1992	1903	1842	1462	1314	810	1146	-1%	34%	57%	38%
Ontario	2781	4394	6447	4865	2902	3793	3930	3660	2922	2588	1647	2287	-1%	32%	58%	38%
Manitoba	357	326	530	413	384	324	239	303	332	145	157	189	14%	55%	34%	38%
Saskatchewan	1903	1457	2388	1918	2070	1472	601	1254	1683	133	650	663	19%	91%	-8%	47%
Alberta	1157	1360	2112	1614	1239	1332	1048	1200	1096	618	563	697	12%	54%	46%	42%

Province/ Territory	No Adaptation ($M)				Reactive ($M)				Proactive ($M)				% Savings (Proactive vs. Reactive)			
	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100
British Columbia	587	2262	2328	1935	667	1748	1209	1308	649	856	666	738	3%	51%	45%	44%
Yukon	7	19	25	19	8	16	9	11	9	5	-1	3	-14%	72%	108%	70%
Northwest Territories	76	159	247	176	94	148	35	92	72	9	35	33	24%	94%	-1%	65%
Nunavut	0	4	6	4	1	3	2	2	0	1	1	1	52%	52%	46%	50%
Canada	8842	14273	19378	15145	9409	12124	9696	10594	8983	6748	4948	6508	5%	44%	49%	39%

[1] Provincial and territorial values may not sum to the national total due to aggregation methods and multi-decade averaging. See section 2.9 for further details on this limitation.

The distribution of spendings and savings varies widely across regions. Larger provinces with extensive infrastructure networks, such as Ontario, Québec, Alberta, and British Columbia, show the highest absolute spending in all scenarios, reflecting both the scale of their asset bases and exposure to intensifying climate hazards. These same regions also benefit substantially from proactive adaptation, with mid-century savings often exceeding 40% or more compared with the reactive adaptation scenario. Atlantic provinces, while facing smaller overall spending levels, exhibit similarly strong proportional benefits from proactive measures, particularly in Nova Scotia, New Brunswick, and Prince Edward Island, where early upgrades help mitigate compounding precipitation-related risks.

More variable patterns emerge in the Prairies and northern territories. Alberta generally follows the national trend, showing clear mid-century benefits from proactive action, while Manitoba sees more moderate but consistent savings. Saskatchewan stands out for its highly variable profile: proactive adaptation nearly eliminates additional costs in 2055, yet by 2085 reactive expenditures decline enough that the advantage of proactive measures narrows. This pattern suggests that proactive strategies deliver the greatest value where climate risks are intensifying and infrastructure density is high.

In the territories, absolute costs remain small, but proportional differences between scenarios fluctuate considerably, with some years showing very high relative savings under proactive adaptation and others showing minimal differences. In a few cases, projected differences between no-adaptation and proactive scenarios appear slightly negative – such is the case in Saskatchewan and Newfoundland and Labrador in specific time horizons. While these results may seem counterintuitive, they are primarily driven by model uncertainty, the timing of asset replacement cycles, and threshold effects (e.g., arbitrary selecting time-horizons) associated with the chosen analysis periods.

Overall, the results highlight the importance of timing and proactive planning. Reactive costs tend to peak mid-century in many regions due to escalating climate stressors and ageing assets. The analysis shows that proactive adaptation helps smooth these peaks, reducing long-term expenditures and providing more predictable financial needs over time. The findings underscore the value of early, targeted investment in climate-resilient infrastructure.

3.3.2 Distribution of Costs Across Levels of Governments

Table 3.15 compares average annual climate-related infrastructure spending across municipal, provincial, and federal governments under three scenarios relative to a stable climate baseline. Average annual spendings presented include both climate-related damage and adaptation investment. Breakdowns of average annual climate-related spending into climate-related damages and adaptation investment for the reactive and proactive adaptation scenarios by level of governments are available in **Table 5-3** and **Table 5-4** of **Appendix A**.

Under the no-adaptation scenario, all levels of government experience a clear upward trend from 2025 to 2085, with costs rising substantially as climate impacts intensify later in the century. Across all three levels of government, the results show broadly similar trends over time: costs rise toward mid-century under the reactive adaptation scenario, reflecting increasing climate pressures and the timing of key replacement cycles, while proactive adaptation produces a consistently declining trajectory that avoids the reactive

mid-century spike. This shared pattern highlights that, regardless of jurisdiction, delaying upgrades tends to create higher and more volatile spending needs, whereas proactive measures smooth expenditures and reduce long-term fiscal exposure to climate risks.

Despite these common trends, the magnitude of spending differs substantially across levels of government. Municipal governments bear by far the largest share of climate-related costs, owing to their extensive infrastructure ownership, including roads, water-related assets, and community facilities. Provincial governments carry the next-largest burden, following similar temporal patterns but with smaller amounts that reflect their more concentrated asset portfolios. Federal spending is smallest overall, showing the same general rise-and-fall pattern but with much lower exposure due to a narrower set of assets. Taken together, these differences reinforce that proactive adaptation delivers benefits for all orders of government, but the scale of those benefits is greatest for municipalities and provinces, where the financial pressures of inaction are most pronounced.

Table 3.15: Average annual spending by level of government compared to no climate change baseline[1]

Level of Governments	No adaptation ($M)				Reactive Adaptation ($M)				Proactive Adaptation ($M)			
	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100
Federal	113	222	312	234	121	184	153	158	138	125	56	101
Provincial	2,506	3,824	5,041	4,027	2,695	3,045	1,736	2,454	2,431	1,324	897	1,388
Municipal	6,223	10,228	14,025	10,884	6,593	8,895	7,808	7,981	6,415	5,299	3,995	5,019
Total	8,842	14,273	19,378	15,145	9,409	12,124	9,696	10,594	8,983	6,748	4,948	6,508

[1] - The distribution of costs across levels of government was calculated by attributing average costs to the current value of infrastructure. However, the results may not fully capture disparities arising from level-specific factors, such as differences in the year of construction and the useful service life of assets

3.3.3 Asset-Specific Costs

Table 3.16 summarizes the projected national annual incremental cost by scenario and asset type, illustrating the scale of savings achievable through proactive adaptation. Breakdowns of average annual climate-related spending into climate-related damages and adaptation investment for the reactive and proactive adaptation scenarios by asset type are available in **Table 5-7** and **Table 5-8** of **Appendix A**. Note that negative percentages indicate cases where proactive adaptation is more expensive than reactive. For all asset types, both reactive and proactive adaptation scenarios lead to a decrease in annual incremental climate-related costs when compared to the no adaptation scenario. These advantages are most pronounced for assets with high exposure and high replacement value, such as roads, water networks, and transit systems, and infrastructure nearing the end of its service life, where upgrades can

efficiently integrate resilience. The benefits compound over time, with proactive adaptation offering significant cost reductions as climate impacts intensify.

Proactive adaptation leads to notable savings by 2085 when compared to the reactive adaptation scenario for road, potable water, wastewater, bridges and tunnel assets. For example, road assets show 71% cost savings in 2055 and 7% in 2085 for proactive adaptation compared to reactive adaptation. Potable water assets achieve 31% savings in 2055 and 69% in 2085, while wastewater assets see 18% and 54% savings over the same periods

Other asset types, such as stormwater, culture/recreation/sports facilities, and public transit, also benefit, though in some cases, proactive adaptation may be more expensive than reactive, as indicated by negative percentages in the table. Savings under the proactive adaptation scenario may vary depending on the concentration of assets with similar remaining service or repair life, which can result in higher cost clustering within the same period compared to the reactive adaptation scenario. This is the case for stormwater, public transit, solid waste and the culture, recreation and sports facilities asset categories.

These results, however, only reflect the costs related to rising heat and extreme rainfall; other climate-driven threats such as more frequent and severe flooding will potentially require additional investment.

Table 3.16: Projected national annual incremental cost by scenario and asset type compared to no climate change baseline

Asset Type	No Adaptation ($B)				Reactive Adaptation ($B)				Proactive Adaptation ($B)				% Savings (Proactive vs. Reactive)			
	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100
Road assets	5.77	7.58	9.88	8.11	6.28	5.99	2.58	4.71	5.34	1.73	2.40	2.76	15%	71%	7%	41%
Potable water assets	0.75	1.57	2.19	1.64	0.76	1.56	1.98	1.56	0.67	1.08	0.61	0.81	12%	31%	69%	48%
Wastewater assets	1.02	2.03	2.96	2.18	1.05	2.02	2.65	2.07	1.24	1.66	1.23	1.40	-18%	18%	54%	32%
Bridge and tunnel assets	0.45	1.16	1.55	1.17	0.46	0.95	0.75	0.77	0.51	0.62	-0.16	0.29	-9%	35%	121%	62%
Stormwater assets	0.33	0.73	0.97	0.74	0.34	0.79	0.92	0.75	0.46	0.73	0.38	0.53	-37%	8%	59%	29%
Culture, recreation and sports facilities	0.29	0.62	1.03	0.71	0.25	0.41	0.35	0.35	0.50	0.34	0.21	0.32	-101%	16%	41%	9%
Public transit assets	0.19	0.51	0.70	0.52	0.23	0.33	0.42	0.35	0.23	0.52	0.23	0.34	3%	-57%	46%	1%
Solid waste assets	0.03	0.07	0.10	0.07	0.03	0.06	0.04	0.04	0.04	0.05	0.04	0.05	-23%	8%	-25%	-8%

3.4 Costs and Benefits of Adaptation

This section evaluates the economic effectiveness of adaptation investments by comparing the Benefit-Cost Ratio (BCR) for various infrastructure asset types under three scenarios: no adaptation, reactive adaptation, and proactive adaptation. These metrics demonstrate where and when investments deliver the greatest return in avoided infrastructure costs.

3.4.1 Proactive vs. Reactive Adaptation: Key Economic Differences

Table 3.17 shows that both adaptation scenarios deliver high returns - each dollar invested avoids multiple dollars in future climate-related costs, with proactive adaptation consistently outperforming reactive. The national-level BCRs reflect the aggregation of asset-specific BCRs, weighted by each asset type's proportion within the national portfolio, based on the current replacement value of the asset types, with the assumption that portfolio composition remains constant. In 2025, BCR is 9.4 for proactive compared to 7.5 for reactive, by end of century, proactive adaptation BCR is 7.6 compared to 6.4 for reactive adaptation. This indicates that proactive adaptation yields roughly 18–25% higher BCR than reactive across the horizon, with the advantage narrowing slightly over time but remaining material.

Across both adaptation pathways, the return on investment declines modestly from 2025 to 2055 before stabilizing toward 2085. The slight mid-century reduction in BCR likely reflects increasing adaptation investments associated with more frequent replacement and replacements.

Table 3.17: Average benefit-cost ratio for reactive and proactive adaptation scenario by time horizon (undiscounted)

	2011-2040	2041-2070	2071-2100	2025-2100
Reactive Adaptation	7.5	6.4	6.4	6.6
Proactive Adaptation	9.4	7.9	7.6	8.1

Table 3.18 presents the share of total public infrastructure that is adapted to climate risks, measured by current replacement value, under the three different scenarios. The table shows how the proportion of adapted infrastructure is expected to evolve nationally over time, with results provided for the years 2025, 2030, 2050, 2070 and 2100.

The results highlight the contrast between adaptation scenarios. Under the no adaptation scenario, the share of adapted infrastructure remains at 0% throughout the period, reflecting no additional resilience measures implemented. In contrast, both reactive and proactive adaptation scenarios show significant increases in the proportion of adapted assets over time. Proactive adaptation doubles progress, reaching 73% by 2050 compared to 31% for reactive adaptation. By 2100, both scenarios achieve adaptation of the majority of assets, with 78% of infrastructure upgraded to withstand climate risks under the reactive and

94% of assets under the proactive adaptation. These findings underscore the importance of early and proactive investment in adaptation to achieve timely and comprehensive resilience across Canada's public infrastructure portfolio.

The BCR is assessed on a prospective basis, which explains why a positive value may be observed even when the proportion of infrastructure adapted to CRV remains limited. Specifically, the BCR simply compares the total avoided losses over the asset's useful service life with the costs required to ensure resilience over that same period. As such, the calculation is agnostic to the asset's current adaptation status. The share of adapted infrastructure is shown as 0% in 2025 due to a simplifying assumption that no infrastructure is considered adapted at the midpoint year (2025) of the 2011–2040 period.

Table 3.18: Share of total adapted infrastructure by current replacement value (%)

	2025	2030	2050	2070	2100
No Adaptation	0%	0%	0%	0%	0%
Reactive Adaptation	0%	4%	31%	53%	78%
Proactive Adaptation	0%	23%	73%	%	94%

3.4.2 Distribution of Adaptation Costs and Benefits Across Levels of Government

Table 3.19 outlines the BCR for each level of government – municipal, provincial and federal – for the reactive and proactive adaptation scenarios. Results show that proactive adaptation consistently yields higher BCR than reactive adaptation across all levels of government and all-time horizons.

Adaptation investments at the federal level yield the highest returns under both scenarios, with BCRs ranging from 9.1 to 8.1 for reactive adaptation and from 11.0 to 9.5 for proactive adaptation between 2025 and 2085. Municipal BCRs are the lowest overall, though they remain positive, while provincial BCRs fall between the two. These differences reflect the varying asset compositions within each level of government's portfolio. Federal and provincial portfolios contain a higher proportion of bridge and tunnel assets, which tend to generate higher BCRs as upgrades to these long-lived, high-value assets produce relatively large avoided-damage benefits. Municipal portfolios, which contain a large proportion of roads assets, generally yield lower BCRs as road assets require more frequent rehabilitation and have shorter service lives, resulting in smaller avoided-cost gains per dollar invested. For detailed asset-level BCR see **Section 3.4.3**.

Across time, the results show a gradual decline in BCRs for both adaptation approaches, suggesting that the relative benefits of investments decrease modestly toward 2085. Despite this decline, most BCRs remain well above 1, indicating that adaptation investments remain economically worthwhile throughout the projection period. The consistent advantage of proactive adaptation, typically 17–26% higher than

reactive BCR, highlights the economic value of acting earlier and planning, rather than responding as impacts occur.

Table 3.19: Average Benefit-Cost Ratio by level of government (undiscounted)

Level of government	Reactive adaptation				Proactive adaptation			
	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100
Municipal	7.0	6.0	6.0	6.2	8.8	7.4	7.1	7.6
Provincial	8.7	7.5	7.5	8.3	10.9	9.4	9.0	9.9
Federal	9.1	8.0	8.1	7.7	11.0	9.7	9.5	9.6
Weighted average	7.5	6.4	6.4	6.6	9.4	7.9	7.6	8.1

3.4.3 Asset-Level Benefit-Cost Ratio Insights

The cost-benefit ratios reported in **Table 3.20** show that both reactive and proactive adaptation generate economic returns across all asset types, with proactive adaptation producing higher ratios. Public transit and bridge and tunnel assets exhibit the strongest returns, followed by water-related assets and road assets. These undiscounted ratios reflect the full value of future avoided damages giving equal weight to a dollar spent in 2100 and in 2025. As a result, asset types with larger long-term sensitivity to temperature and precipitation, such as public transit systems and bridges and tunnels, which incur substantial climate-related deterioration costs when left unadapted, show especially high undiscounted ratios because early upgrades prevent a larger volume of future damage.

In practice, governments apply discount rates to incorporate considerations such as opportunity costs, risk, and intertemporal preferences when valuing future costs and benefits. A higher discount rate places less weight on benefits that occur far in the future, making long-term avoided damage appear smaller in today's terms. Public infrastructure appraisals often use rates around 8% to reflect the opportunity cost of public funds, whereas climate-adaptation assessments frequently rely on much lower rates, typically around 2%, to account for intergenerational equity and the potential for severe future climate damage that would otherwise be undervalued. Because of this, the choice of discount rate will meaningfully alter both the magnitude of the calculated return on investment and the timing at which adaptation measures appear cost-effective.

Applying a 2% discount rate preserves many of the patterns observed in the undiscounted results (**Table 3.21**). Proactive adaptation continues to outperform reactive approaches for nearly all asset types, and transport and water assets maintain the highest returns. Under this low discount rate, adaptation strategies with benefits that accrue several decades into the future still show strong performance, and the relative ranking across asset categories stays broadly consistent with the undiscounted case.

In contrast, applying an 8% discount rate significantly reduces the return on investment for both proactive and reactive adaptation, particularly for assets whose benefits occur later in the century (**Table 3.21**). In many cases, proactive adaptation continues to yield higher ratios than a reactive approach, but the margin narrows considerably. These results illustrate that when future benefits are heavily discounted, long-term avoided damages play a much smaller role in the economic appraisal of adaptation, potentially shifting priorities toward measures with more immediate or short-term returns.

Table 3.20: Average Benefit-Cost Ratio by asset type – discount rate of 0%

Asset Type	Reactive Adaptation				Proactive Adaptation			
	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100
Road assets	5.4	4.3	4.3	4.5	7.3	5.7	5.4	5.9
Bridge and tunnel assets	14.2	13.2	13.9	13.7	16.7	16.2	16.1	16.3
Public transit assets	24.2	16.5	13.3	16.9	33.1	20.0	17.2	21.7
Potable water assets	6.7	6.2	6.4	6.4	8.4	7.7	7.6	7.8
Wastewater assets	6.1	5.8	6.1	6.0	6.9	6.6	6.6	6.7
Stormwater assets	6.6	6.4	6.6	6.5	7.7	7.3	7.3	7.4
Solid waste assets	4.9	3.5	2.9	3.6	5.4	3.7	3.3	3.9
Culture, recreation and sports facilities	6.0	5.1	5.5	5.5	6.4	6.3	6.2	6.3

Table 3.21: Average Benefit-Cost Ratio by asset type and discount rates (0%, 2% and 8%)

Asset Type	Reactive Adaptation 2025-2100			Proactive Adaptation 2025-2100		
	0%	2%	8%	0%	2%	8%
Road assets	4.5	2.5	1.1	5.9	3.4	1.5
Bridge and tunnel assets	13.7	7.4	3.1	16.3	8.9	3.7
Public transit assets	16.9	10.0	4.8	21.7	13.2	6.8
Potable water assets	6.4	3.5	1.5	7.8	4.3	1.8
Wastewater assets	6.0	3.2	1.3	6.7	3.6	1.5
Stormwater assets	6.5	3.5	1.4	7.4	4.1	1.7
Solid waste assets	3.6	2.1	1.0	3.9	2.3	1.1
Culture, recreation and sports facilities	5.5	3.0	1.3	6.3	3.4	1.4

3.5 Implications of Alternative Climate Futures and Emissions Pathways

Table 3.22 introduces the range of possible average annual climate-related costs (increased replacement, repair and O&M) for Canadian public infrastructure under the no adaptation strategy, spanning the period from 2025 to 2100, compared to a stable climate scenario. The table presents cost projections across

three emissions scenarios: low (SSP1-2.6), medium (SSP2-4.5), and high (SSP3-7.0) reflecting the uncertainty inherent in future climate outcomes.

Results show that projected climate-related costs are highly sensitive to future emissions. Costs roughly double from low to medium emissions scenario ($7.39B to $15.15B) and then more than double again to high emissions ($38.61B) scenario, making the high emission outcome about 5.2 times the low emission scenario.

Table 3.22: Projected incremental annual climate-related costs for public infrastructure (under the no adaptation scenario (2025-2100, $B, 50th percentile)

Low Emission	Medium Emission	High Emission
7.39	15.15	38.61

Table 3.23 introduces the range of possible average annual climate-related costs - including both climate-related costs and adaptation costs - for Canadian public infrastructure under the proactive and reactive scenarios, spanning the period from 2025 to 2100. The table presents cost projections across three emissions scenarios -low, medium, and -high reflecting the uncertainty inherent in future climate outcomes. This approach provides a view of the potential financial risks, highlighting a plausible range of outcomes.

Table 3.23: Range of possible average annual climate-related costs under the proactive and reactive adaptation scenarios (2025 - 2100, $B)

Proactive Adaptation			Reactive Adaptation		
Low Emission	Medium Emission	High Emission	Low Emission	Medium Emission	High Emission
3.04	6.51	15.17	4.59	10.59	23.14

3.6 Flood Adaptation

This section summarizes the findings of the dedicated flood-risk analysis, which examined how climate-driven changes in riverine and surface flooding, as well as related infrastructure failures such as sewer backup, are expected to affect future damage. Unlike the deterioration-based modelling for heat and precipitation, the flood analysis evaluated event-driven losses and the potential benefits of structural flood-protection measures. The results presented here highlight three core elements:

- an overview of historical flood and sewer-back-related damages up across Canada;
- projected increases in flood-related damages and sewer-back up under a no-adaptation scenario, with climate change; and
- the scale of avoided losses achievable through targeted flood-protection investments.

Together, these findings illustrate how flood adaptation complements the broader climate-driven deterioration analysis by capturing a major category of climate risk not represented in the asset-level lifecycle modelling.

3.6.1 Historical Flood-related Damages

Flooding is one of the most significant and costly climate-related hazards affecting Canadian public infrastructure (Public Safety Canada, 2024). This section presents a summary of historical water-related insurance losses across Canada using data from 2016 to 2024. The analysis includes losses associated with overland flooding and sewer backup, based on claims data compiled from CatIQ's Historical Catastrophe Database and Industry Exposure Database. All claim totals represent incurred costs for closed claims.

Figure 3.5 illustrates the total value of flood-related and sewer-backup-related insurance claims aggregated to the provincial scale. The results show a clear concentration of water-related losses in a small number of provinces. Ontario records the highest combined losses, with a substantial contribution from sewer-backup claims in addition to overland flood losses. Alberta follows, driven primarily by flood-related claims. Quebec also exhibits high total losses, with contributions from both perils. Saskatchewan, Nova Scotia, British Columbia, and Manitoba show lower but measurable totals for the combined period. Prince Edward Island, Newfoundland and Labrador, and New Brunswick exhibit comparatively minimal water-related claim totals. It should be noted that total losses can obscure the fact that smaller provinces may have higher per-capita losses. See Figure 6-2 in **Appendix B** for an overview of per-capita losses for sewer back-up by province.

The figure provides a consolidated view of the relative magnitude of water-related losses across provinces. Differences between provinces reflect variation in the frequency and severity of past water-related events, the distribution of insured assets, and the historical patterns captured in the insurance claims record. Additional data regarding historical flood-related damage can be found **Appendix B**.

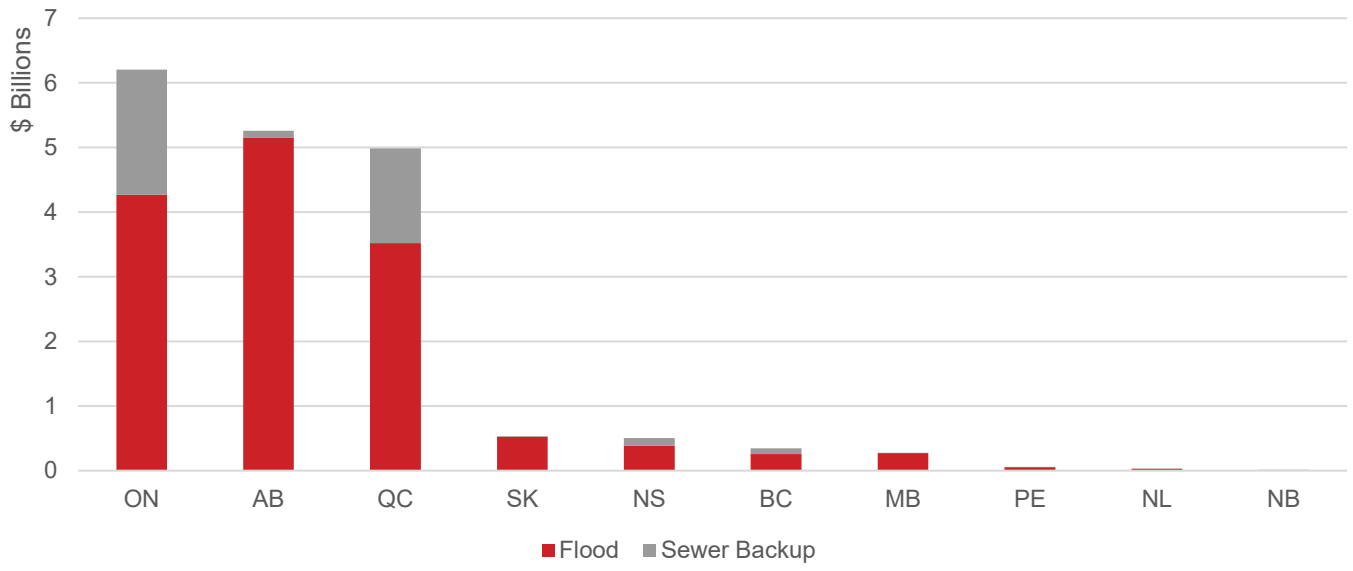

Figure 3.5: Historical insurance water-related claims in Canada between 2016 and 2024, per province

3.6.2 Flood-Related Damages – No Adaptation Scenario

Under a no-adaptation scenario, projected damages from flooding and sewer backup rise over time. **Figure 3.6** shows Average Annual Losses increase across all provinces and territories, with the most pronounced impacts in densely populated regions such as Ontario, Quebec, and British Columbia. While both flooding and sewer-backup damages grow over the projection period, the figure indicates that flooding remains the dominant driver of total losses, with sewer-backup contributing a smaller share that varies by jurisdiction.

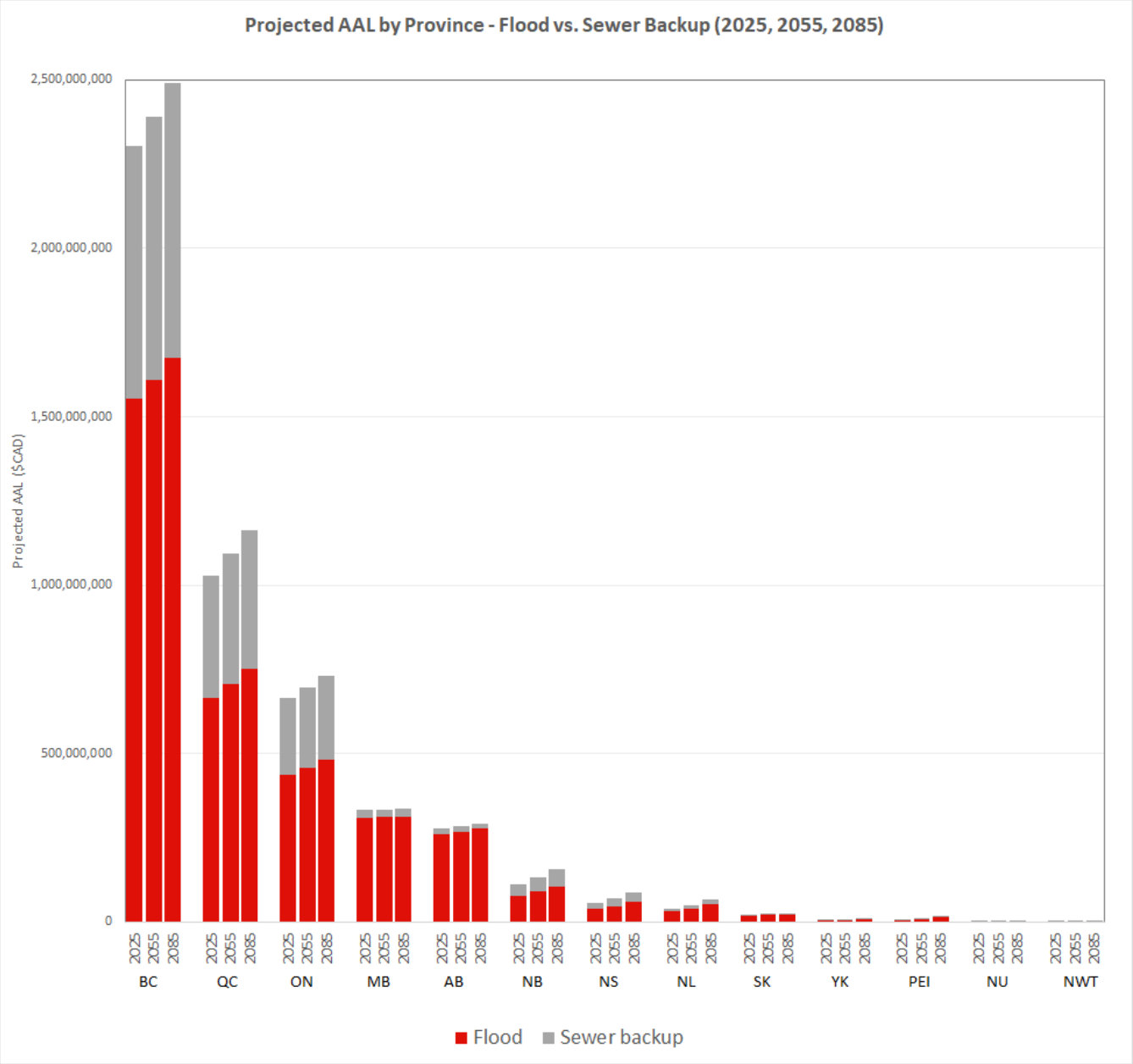

Figure 3.6: Projected damage related to flooding and attribution to public infrastructure failure (without adaptation: 2025, 2055 & 2085)

3.6.3 Flood-Related Damages by Adaptation Scenario

This section introduces the results of the flood-adaptation analysis by comparing projected damages and costs across two scenarios: no adaptation and proactive adaptation. **Table 3.24** summarizes these projections for 2085, providing a jurisdiction view of expected damages, adaptation expenditures, and the resulting savings. The table helps illustrate where early investments in resilience yield the greatest returns, particularly in regions with high exposure to water-related hazards.

Two adaptation scenarios were evaluated. In the no-adaptation case, buildings remain as originally constructed; results show total water-damage losses with no adaptation spending. In the proactive adaptation scenario, at-risk buildings are protected in advance, primarily through elevation or other localized protection measures, such as small-scale floodwalls, localized berms, or site-specific barriers, as outlined in **Section 2.8**. For this scenario, the results report both (1) remaining (residual) damage and (2) the capital cost of protection. Avoided losses are measured relative to the no-adaptation baseline. These definitions align with the approach commonly used in national-scale flood-risk assessments.

Table 3.24: Summary of projected flood-related costs (damage and mitigation) by jurisdiction (no adaptation and proactive)

	No Adaptation ($M)				Proactive ($M) (Damage only)				Proactive ($M) (Adaptation Costs)				Savings ($M)			
	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100
Newfoundland and Labrador	39	50	61	52	36	48	59	50	0	0	0	0	3	3	2	3
Prince Edward Island	6	9	12	10	6	8	11	9	0	0	0	0	0	1	1	1
Nova Scotia	56	70	84	73	46	60	74	63	4	0	0	1	5	10	10	9
New Brunswick	112	132	152	136	71	92	115	97	13	0	0	3	29	40	37	37
Québec	1027	1094	1158	1105	465	531	595	542	150	0	0	32	412	563	563	531
Ontario	665	697	730	703	300	345	390	353	47	0	0	10	318	352	340	340
Manitoba	333	334	336	335	48	49	50	49	39	0	0	8	246	285	286	277
Saskatchewan	20	21	22	21	11	12	13	12	0	0	0	0	8	9	9	9
Alberta	276	284	292	285	149	165	182	168	33	0	0	7	94	119	110	110
British Columbia	2303	2391	2485	2410	323	406	494	423	2216	0	0	467	-237	1985	1991	1520
Yukon	7	8	10	9	6	8	9	8	0	0	0	0	0	0	0	0
Northwest Territories	1	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0
Nunavut	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
Total Canada	4845	5092	5343	5139	1463	1725	1993	1776	2504	0	0	527	879	3366	3350	2836

Not all provinces show savings from proactive adaptation in the results. This occurs for two reasons. First, the modelling only applied adaptation measures when they deliver a positive return on investment; where adaptation costs exceed expected benefits under modelled conditions, no adaptation is assumed. Second, the analysis relies on average annual losses at the 50th percentile for a mid-range climate scenario. This approach does not capture extreme local events or tail-risk outcomes, and therefore likely underestimates true flood damages in many areas. As a result, the model may identify certain regions as non-viable for adaptation even though real-world risks, especially those involving catastrophic events or cumulative impacts, could strongly suggest the need for adaptation. The projections also do not reflect future growth in the number of buildings.

Despite these limitations, the overall findings are clear. Proactive adaptation delivers the greatest long-term benefit: it reduces the expected total damage, limits public and private financial exposure, and directs resources to the regions and asset types most at risk. Early, coordinated investment in flood protection infrastructure or building flood protection measures avoids higher costs to private property and more severe impacts in the decades ahead.

4. Conclusion

This report documents the analytical framework and modelling results that underpin the findings presented in the Canadian Climate Institute's *Prepare or Repair* report. Using national infrastructure inventories, deterioration models, and climate-adjusted hazard projections, the analysis estimates how climate change is expected to affect the long-term costs of maintaining and renewing Canada's public infrastructure

The modelling results presented in **Section 3** show that existing infrastructure asset pressures associated with aging systems and long-standing reinvestment gaps, are amplified under future climate conditions. Across all regions and asset classes, rising temperatures and more frequent extreme rainfall accelerate deterioration, shorten useful service lives, and increase maintenance, rehabilitation, and replacement needs relative to the stable-climate baseline.

Across the suite of adaptation scenario results, the findings show that climate-driven cost increases are substantial. Under the no-adaptation pathway specifically, total annual infrastructure costs rise steadily throughout the century, adding billions of dollars per year to the fiscal burden borne by governments - especially municipalities, which own the majority of Canada's most climate-sensitive assets.

At the same time, the combined modelling of climate-adjusted deterioration and adaptation pathways demonstrates that proactive adaptation reduces long-term lifecycle costs relative to both reactive and no-adaptation pathways. By upgrading assets to climate-resilient standards at the earliest feasible intervention point, proactive adaptation slows deterioration, reduces the likelihood of climate-driven failures, and avoids the steep cost escalation observed when upgrades are delayed or are not implemented. The slower rate of deterioration, the lower incidence of climate-related failures, and the reduced long-term cost burden compared with the reactive and no-adaptation scenarios are most pronounced through the mid-century period, when climate impacts intensify and many assets reach key renewal points. The analysis also showed that early investments allow the share of climate-resilient infrastructure to increase rapidly, reducing exposure to worsening hazards over the analysis horizon.

Benefit-cost analysis indicated that, even under conservative assumptions, proactive adaptation yielded strong near- and medium-term returns across major asset categories, driven by avoided deterioration, avoided emergency repair, and reduced premature replacement. While the overall results show an uptick in late-century BCRs, reflecting cumulative avoided damages and long-term benefits, this pattern is not uniform across all assets. Several asset types, such as long-lived linear infrastructure and facilities with relatively high adaptation intervention costs, continue to exhibit declining BCRs toward the end of the century due to escalating adaptation costs, diminishing marginal avoided damages, or shifts in climate exposure profiles (see Section 3.4). These patterns highlight the need to interpret BCRs in the context of both timing and asset characteristics.

Taken together, the results support three central technical conclusions. First, climate change significantly increases the lifecycle costs of public infrastructure and the ongoing costs for governments of public infrastructure ownership and operation, without adaptation. Second, proactive adaptation lowers

cumulative costs and accelerates the transition to a more climate-resilient asset base. Third, delaying adaptation via a reactive approach allows deterioration to compound under worsening climate conditions, leading to higher intervention costs - particularly through mid-century, when asset renewal needs peak, although still reducing costs relative to a no-adaptation scenario. It is also important to highlight that public infrastructure costs for governments increase across all adaptation scenarios, and that proactive adaptation serves to minimize, not prevent, these costs.

Bibliography

Beck, H. E. (2023). High resolution one kilometre Köppen Geiger climate classification maps for 1901 to 2099 based on constrained CMIP6 projections. *Scientific Data*, Article 724.

Cannon, A. J. (2020). *Climate-Resilient Buildings and Core Public Infrastructure: An assessment of the impact of climate change on climatic design data in Canada.* Retrieved from Government of Canada: https://climate-scenarios.canada.ca/?page=buildings-report

Catastrophe Indices & Quantification Inc. [CatIQ]. (2024). *Industry Exposure Database (IED) and Historical Catastrophe Database*. Retrieved from CatIQ: https://www.catiq.com

Environment and Climate Change Canada. (n.d.). CMIP6 technical notes. Climate Scenarios Canada. Retrieved from https://climate-scenarios.canada.ca/?page=cmip6-technical-notes

FCM. (2020). *The Cost of Climate Adaptation.* Ottawa: FCM.

Government of Canada, Agriculture and Agri-Food Canada, Science and Technology Branch. (2013). *Terrestrial Ecozones of Canada*. Retrieved from Government of Canada: https://agriculture.canada.ca

Han, Z., Mahinthakumar, G., & Meentemeyer, R. K. (2020). Household behavioral responses to sea-level rise: An agent-based modeling approach for coastal adaptation. *Environmental Modelling & Software*, 104667. doi: https://doi.org/10.1016/j.envsoft.2020.104667

Insurance Bureau of Canada. (2022). *Severe Weather in 2021 Caused $2.1 Billion in Insured Damage*. Retrieved July 29, 2024, from https://www.ibc.ca/news-insights/news/severe-weather-in-2021-caused-2-1-billion-in-insured-damage

Keller, K., Hall, M., Kim, S.-R., Bradford, D. F., & Oppenheimer, M. (2008). Avoiding dangerous anthropogenic interference with the climate system. *Climatic Change*, 275–298. doi: https://doi.org/10.1007/s10584-008-9424-8

Maadani, O. S. (2021). Climate change challenges for flexible pavement in Canada: An overview. *Journal of Cold Regions Engineering*, 35(4).

Natural Earth. (2023). *1:10m physical vectors: Rivers, lakes, and hydrology datasets.* Retrieved from https://www.naturalearthdata.com

Natural Resources Canada. (2023). *Geospatial hydrology layers (national hydro network).* Retrieved from Government of Canada: https://open.canada.ca

Natural Resources Canada. (2022). *Canadian Digital Elevation Model (CDEM).* Retrieved from Government of Canada: https://open.canada.ca

Ness, R., Carriere, Z., & Gauer, V. (2026). *Prepare or Repair: How climate-proofing public infrastructure pays off.* Canadian Climate Institute. Retrieved from Preparing Canada's infrastructure for a changing climate | Canadian Climate Institute

Ness, R., Miller, S., Florez Bossio, C., Pelai, R., & Carriere, Z. (2025). *Close to Home: How to build more housing in a changing climate.* Ottawa, ON: Canadian Climate Institute. Retrieved from https://climateinstitute.ca/wp-content/uploads/2025/02/Close-to-Home-Report-Canadian-Climate-Institute.pdf

Neumann, J. E., Chinowsky, P., Helman, J., Black, M., & Ludwig, L. (2020). Economic risks of coastal flooding and the benefits of adaptation in the United States. *Climatic Change, 160*(2), 251–269. doi: https://doi.org/10.1007/s10584-020-02670-0

Neumann, J. E., Hudgens, D. E., Herter, J., & Martinich, J. (2010). The economics of adaptation along developed coastlines. *Wiley Interdisciplinary Reviews: Climate Change, 2*(1), 89–98. doi: https://doi.org/10.1002/wcc.90

Nicholls, R. J., & Tol, R. S. (2006). Impacts and responses to sea-level rise: A global analysis of the SRES scenarios over the twenty-first century. *Philosophical Transactions of the Royal Society A, 364*(1841), 1073–1095. doi: https://doi.org/10.1098/rsta.2006.1754

PIEVC Alliance and Climate Risk Institute. (2025). *PIEVC Meta-Analysis – Volume 3: The Role of Codes and Standards.* Climate Risk Institute.

Public Safety Canada. (2024). National Risk Profile: First public report (Revised January 2024). Government of Canada. Retrieved from: https://publications.gc.ca/collections/collection_2024/sp-ps/PS1-27-2024-eng.pdf

Sharmin, D. F. (2026). A systematic review of the impacts of climate change on critical infrastructure in Canada. *Environmental Management*, 76,103.

Statistics Canada. (2025, June 24). *Canada's Core Public Infrastructure Survey: Required renewal budgets, 2022*. Retrieved from https://www150.statcan.gc.ca/n1/daily-quotidien/250624/dq250624b-eng.htm

Yohe, G., Neumann, J., & Marshall, P. (1995). The economic cost of greenhouse-induced sea-level rise for developed property in the United States. *Climatic Change, 29*(4), 409–433. doi: https://doi.org/10.1007/BF01092493

Appendices

Appendix A – Supplementary Results

This appendix provides additional supplementary results of the study. Information regarding each of these tables can be found and referenced throughout the report.

Table 5.1: Projected total cost increase between 2025 and 2085, relative to 2025, under the no adaptation scenario

Province / Territory	Cost Increase
Yukon	46%
Newfoundland and Labrador	45%
Ontario	38%
Quebec	37%
Northwest Territories	35%
Nova Scotia	34%
New Brunswick	34%
Canada	31%
British Columbia	29%
Alberta	28%
Nunavut	27%
Manitoba	19%
Prince Edward Island	19%
Saskatchewan	14%

Table 5.2: Proportion of projected incremental cost borne by different levels of government (No Adaptation - Annual) [3]

	Federal Government				Provincial and Territorial Government				Local and Regional Government			
	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100
Road assets	36.1%	24.3%	22.5%	26.1%	82.2%	70.8%	70.0%	72.9%	59.0%	47.1%	44.8%	48.7%
Potable water assets	5.1%	5.4%	5.4%	5.3%	0.2%	0.3%	0.3%	0.3%	11.9%	15.1%	15.4%	14.5%
Wastewater assets	6.8%	6.9%	7.2%	7.0%	0.3%	0.4%	0.4%	0.4%	16.2%	19.5%	20.8%	19.3%
Bridge and tunnel assets	22.1%	29.2%	27.6%	27.1%	12.3%	20.9%	21.1%	19.1%	1.9%	3.0%	2.9%	2.7%
Stormwater assets	3.2%	3.6%	3.4%	3.5%	1.9%	2.7%	2.7%	2.6%	4.5%	6.0%	5.8%	5.6%
Culture. recreation. and sports facilities	18.8%	20.4%	24.0%	21.5%	1.1%	1.5%	1.9%	1.5%	3.9%	5.1%	6.1%	5.3%
Public transit assets	4.0%	5.5%	5.4%	5.1%	1.8%	3.2%	3.3%	2.9%	2.2%	3.7%	3.7%	3.4%
Solid waste assets	3.9%	4.7%	4.5%	4.5%	0.2%	0.3%	0.3%	0.3%	0.4%	0.5%	0.5%	0.5%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 5.3: Adaptation investments and climate-related damages by level of governments for reactive adaptation ($M)[4]

Level of government	Reactive adaptation							
	Adaptation investments				Climate-related damages			
	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100
Municipal	554	1,940	2,706	1,950	6,258	6,838	4,314	5,720
Provincial	196	688	960	692	2,222	2,427	1,531	2,030
Federal	15	51	71	51	164	179	113	150
Total	765	2,679	3,737	2,694	8,644	9,445	5,959	7,900

[3] The distribution of costs across levels of government was calculated by attributing average costs to the current value of infrastructure. However, the results may not fully capture disparities arising from level-specific factors, such as differences in the year of construction and the useful service life of assets

Table 5.4: Adaptation investments and climate-related damage by level of governments for proactive adaptation ($M) [4]

Level of government	Proactive adaptation							
	Adaptation investments ($M)				Climate-related damages ($M)			
	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100
Municipal	2,224	3,406	2,961	2,982	4,280	1,480	621	1,730
Provincial	790	1,209	1,051	1,058	1,519	525	220	614
Federal	58	89	78	78	112	39	16	45
Total	3,072	4,704	4,090	4,118	5,911	2,044	858	2,390

Table 5.5: Adaptation investments and climate-related damages by provinces and territories for reactive adaptation ($M)[4]

Province/Territory	Reactive adaptation							
	Adaptation investments ($M)				Climate-related damages ($M)			
	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100
Newfoundland and Labrador	3.3	14.5	23.6	15.7	31.6	45.8	54.4	46.2
Prince Edward Island	2.1	8.2	10.4	7.8	23.7	30.6	5.8	19.4
Nova Scotia	4.2	16.8	21.2	15.9	30.1	48.0	21.3	33.7
New Brunswick	11.7	46.4	59.3	44.2	71.9	107.7	48.0	76.6
Quebec	99.2	378.2	563.5	392.6	1,344.4	1,613.7	1,340.0	1449.0
Ontario	182.0	690.9	1,012.7	710.8	2,719.7	3,102.4	2,917.6	2948.9
Manitoba	26.1	79.8	112.8	81.5	357.4	244.5	126.5	221.7
Saskatchewan	171.1	445.8	587.6	443.9	1,899.2	1,026.4	13.4	810.3
Alberta	95.4	309.3	447.5	318.8	1,143.1	1,022.9	600.8	881.6
British Columbia	97.7	389.2	558.1	394.5	569.3	1,358.8	651.3	913.3
Yukon	3.2	10.4	12.3	9.6	4.5	5.8	-	3.2
Northwest Territories	10.9	36.6	42.6	33.6	83.3	111.2	-	61.4
Nunavut	0.3	2.1	3.0	2.1	0.4	0.6	-	0.3

[4] Additional methodological considerations apply to the disaggregated results in Tables 5-5, 5-6, 5-7 and 5-8. Climate-related damages are defined as incremental life-cycle costs under reactive and proactive adaptation, minus adaptation investment costs, both measured relative to the stable-climate reference case. This calculation can produce slightly negative residuals. These arise when adaptation shifts replacement or retrofit timing in ways that eliminate repairs that would otherwise occur in the stable-climate baseline, and when results are averaged across multi-decade reporting periods (2011–2040, 2041–2070, 2071–2100), which can lower period-average residual costs when adaptation occurs early in the interval. These values reflect timing interactions and temporal aggregation rather than changes in modeled performance. To maintain interpretability, residual negatives were set to zero at the provincial and asset-type level. As a result, provincial totals do not sum exactly to the national total, which is calculated independently from fully aggregated cost streams. The deviation is under ten percent.

Table 5.6: Adaptation investments and climate-related damages by provinces and territories for proactive adaptation ($M)[4]

Province/Territory	Proactive adaptation							
	Adaptation investments ($M)				Climate-related damages ($M)			
	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100
Newfoundland and Labrador	17.8	25.2	24.0	23.2	23.5	18.3	6.6	14.8
Prince Edward Island	8.6	12.3	11.1	11.0	13.0	4.4	3.0	5.7
Nova Scotia	17.7	25.9	22.5	22.8	15.0	16.1	7.2	12.4
New Brunswick	49.1	73.1	63.8	64.4	33.7	19.8	-	14.9
Quebec	474.0	768.7	651.1	660.2	987.7	545.0	158.9	485.8
Ontario	865.4	1,395.9	1,158.3	1190.4	2,056.3	1,192.4	488.6	1096.5
Manitoba	93.6	134.2	117.8	119.2	238.1	10.6	39.5	69.9
Saskatchewan	526.8	640.5	607.6	603.6	1 156.0	-	42.0	259.9
Alberta	369.9	564.3	479.0	489.7	726.2	53.3	83.6	206.9
British Columbia	398.7	671.8	618.7	593.4	250.3	184.2	47.7	144.2
Yukon	7.6	11.4	12.8	11.1	1.2	-	-	0.3
Northwest Territories	30.7	37.5	47.7	40.1	41.0	-	-	8.6
Nunavut	1.8	2.8	2.5	2.5	-	-	-	0.0

Table 5.7: Adaptation investments and climate-related damage by asset type for reactive adaptation ($M)[4]

Province/Territory	Reactive adaptation							
	Adaptation investments ($M)				Climate-related damages ($M)			
	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100
Road assets	658	1,883	2,276	1,780	5,619	4,108	308	2,926
Bridge and tunnel assets	28	94	104	84	437	859	649	687
Public transit assets	21	94	123	90	210	237	298	255
Potable water assets	6	98	297	157	754	1,466	1,685	1,402
Wastewater assets	28	150	394	221	1,025	1,873	2,254	1,845
Stormwater assets	5	134	242	149	333	660	682	600
Solid waste assets	8	23	31	23	26	33	4	20
Culture, recreation and sports facilities	27	108	172	116	222	304	177	237

Table 5.8: Adaptation investments and climate-related damage by asset type for proactive adaptation ($M)[4]

Province/Territory	Proactive adaptation							
	Adaptation investments ($M)				Climate-related damages ($M)			
	2011-2040	2041-2070	2071-2100	2025-2100	2011-2040	2041-2070	2071-2100	2025-2100
Road assets	1,873	2,201	2,211	2,136	3,468	-	194	807
Bridge and tunnel assets	259	322	100	221	248	298	-	170
Public transit assets	101	157	117	129	124	362	111	213
Potable water assets	89	541	489	425	576	543	126	385
Wastewater assets	337	632	689	592	903	1,031	542	811
Stormwater assets	173	446	292	328	288	287	84	207
Solid waste assets	22	27	32	28	20	25	12	19
Culture, recreation and sports facilities	322	267	157	235	178	78	51	88

Appendix B – Flood-Related Historical Losses and Flood Modelling Framework

This appendix summarizes additional data concerning historical distribution of water-related insurance losses across Canada between 2016 and 2024 and outlines the analytical framework used to model structural flood-protection measures. The historical loss data establish a baseline for understanding how flood and sewer-backup damages have varied across provinces. These patterns inform the modelling of potential protective infrastructure by identifying where flood and sewer-related exposure has been most concentrated.

Historical Loss Distribution (2016-2024)

Historical water-related claims were compiled from CatIQ's Historical Catastrophe Database and Industry Exposure Database. Losses include incurred costs for closed claims associated with overland flooding and sewer backup. All claims were aggregated at the Forward Sortation Area level and then summed to the provincial scale to ensure consistent geographic comparison.

Figure 6-1 presents the cost-weighted mix of losses across provinces. Losses are separated by Line of Business and Exposure Peril, including personal flood, auto flood, personal sewer backup, commercial flood, and commercial sewer backup. For each province, the total cost of closed claims are computed and the proportional share of each category is shown.

The figure shows that the composition of flood-related losses differs across provinces. Ontario and Quebec show a larger share of sewer-backup losses within the personal insurance category. Alberta and Saskatchewan show higher proportions of commercial flood losses. These patterns represent the types of water-related events recorded in the claims data and the insured assets affected in each region.

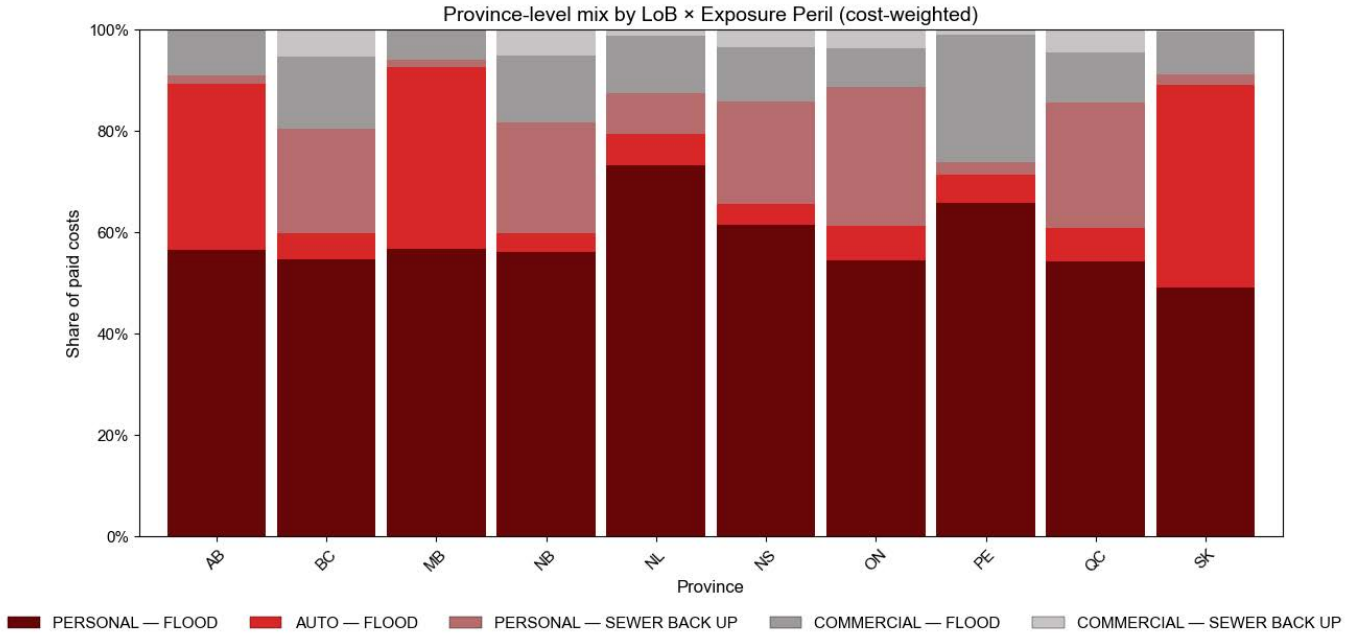

Figure 6-1 Province-level cost-weighted mix of historical losses (2016-2024) by Line of Business and Exposure Peril

Figure 6-2 shows per-capita sewer-backup losses over the same period. Quebec has the highest per-capita cost at $162. Ontario records $121 and Nova Scotia $112. Alberta and British Columbia record $21 and $16 respectively. Manitoba and New Brunswick show $3 each.

These results quantify the relative scale of sewer-backup losses across provinces, complementing the composition data in Figure 3-5 by expressing losses on a per-resident basis.

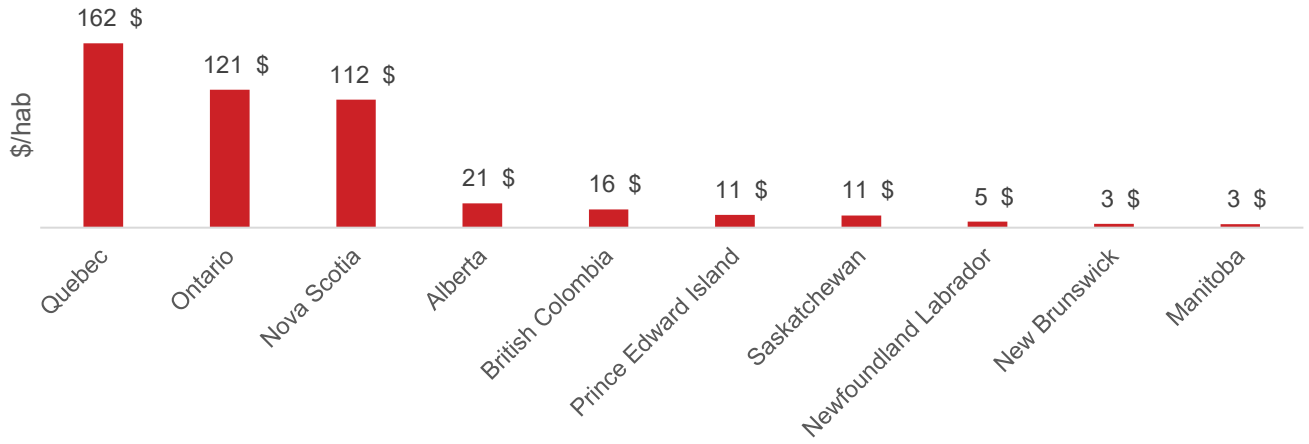

Figure 6-2 Sewer backup claims per capita per province between 2016 and 2024

Flood-Protection Modelling Framework

As flooding is event-driven and influenced by hydrodynamics, shoreline configuration, terrain elevation, and local connectivity, it cannot be represented using the deterioration modelling applied to temperature- and precipitation-induced asset wear. A dedicated flood-protection framework was used to evaluate where structural measures may reduce projected damages.

The analysis estimates where shoreline armouring, beach nourishment, or structure elevation may reduce future waterbody-driven flood losses. Flooding due to drainage failure or sewer surcharge is not included in the protection modelling.

Adaptation Decision Structure

The modelling incorporates established economic frameworks used in flood and coastal protection studies (Han, Mahinthakumar, & Meentemeyer, 2020; Keller, Hall, Kim, Bradford, & Oppenheimer, 2008; Yohe, Neumann, & Marshall, 1995; Nicholls & Tol, 2006; Neumann, Hudgens, Herter, & Martinich, 2010; Neumann, Chinowsky, Helman, Black, & Ludwig, 2020). Behaviour-specific approaches requiring parcel-level parameters are not used due to unavailable data. The model applies a decision rule in which a protective measure is implemented when avoided flood losses exceed life-cycle costs.

The measures represented include shoreline armouring such as seawalls, dikes, and revetments, beach nourishment, and elevation of structures. Strategic retreat is not evaluated because parcel-value data is not available at the national scale. Measures are assessed at the shoreline or river-segment scale because water levels affect multiple buildings through common hydraulic pathways.

Inundation Modelling

Flood depth projections from the Canadian Climate Institute (Ness, Clark, Bourque, Coffman, & Beugin, 2021; Ness, Miller, Florez Bossio, Pelai, & Carriere, 2025) were combined with hydrographic layers, digital elevation models, and exposure data from CatIQ.

Only waterbody-driven flooding is modelled. A smoothed shoreline elevation surface is created from Digital Elevation Models. Projected water-surface levels are produced by adding flood depths to shoreline elevations. Inundation occurs where ground elevation is below the computed water surface and hydraulically connected to the shoreline. Hydraulic connectivity is evaluated by propagating inundation inland through valid terrain pathways. Inundation is computed under both undefended and defended conditions. Avoided inundation equals the difference between these two states.

Cost Modelling

Costs for protective works follow published Canadian and international shoreline-management literature:

- Armouring and floodwalls use cost estimates synthesized by Natural Resources Canada (Natural Resources Canada, 2022), with capital costs represented at approximately 1,000 dollars per linear foot and annual maintenance at four percent of capital cost.
- Beach nourishment uses cost formulations from Nicholls & Tol (2006) and Neumann, Hudgens, Herter, & Martinich (2010).
- Structure elevation uses a representative cost of 50,000 dollars per building (Neumann, Chinowsky, Helman, Black, & Ludwig, 2020).

All costs are converted to 2025 dollars using CPI normalization and present-value factors.

Assignment of Benefits

Avoided losses are assigned to protective segments based on shortest hydraulic connection. Segment-level protection occurs where aggregated avoided losses exceed the life-cycle cost of the protective option. Elevation is evaluated for individual buildings where shoreline protection is not economically viable. No abandonment pathways are modelled due to data limitations.

Analytical Boundaries

The modelling does not incorporate wave dynamics, erosion, sediment transport, stormwater behaviour, or behavioural variability among property owners. Existing local protective works are not explicitly represented. Protective options reflect potential interventions based on available data.

Integration with the Broader Assessment

This analysis complements the deterioration-based modelling of temperature- and precipitation-related impacts by capturing a separate category of climate risk requiring new protective infrastructure rather than upgrades to existing assets. Combined, these components provide a more complete assessment of Canada’s long-term infrastructure adaptation needs.

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